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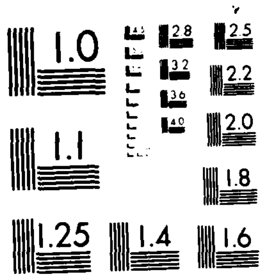

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BIOLOGY, MANAGEMENT AND UTILIZATION OF COMMON REED

Phragmites australis

by

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Final technical report

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Chapter 1

Introduction

1.1 Background

The common reed, *Phragmites australis* (Cav.) Trin. is a helophytic grass having a world-wide distribution. It generally inhabits wetlands, where under the proper conditions it may flourish and become the dominant plant species. Its survival and reproduction strategies make it also one of the first invaders in newly reclaimed wetlands as dredged material disposal sites or new-born polders. Despite its apparently aggressive growth, reeds do not normally invade healthy wetlands and displace other plant species. Reeds dominate a wetland only after a disturbance such as drainage or pollution. The common reed is able to withstand extremes of environmental conditions, including the presence of toxic contaminants. *Phragmites australis* is the dominant plant species on most Corps of Engineers (CE) dredged material disposal sites, particularly on the wetland-creation and confined upland disposal sites containing contaminated dredged materials.

Many of these sites have become prolific wildlife habitats,despite the presence of highly-contaminated dredged material placed within. Section 404 of the Clean Water Act, Public law 92-500, requires that environmental evaluations of dredged material discharge include the effects of disposal on "contaminant-concentration through biological processes". Therefore, the CE Districts have a crucial need to predict the bio-accumulation of contaminants in plants and animals that establish residence on wetland-creation and confined upland disposal sites containing contaminated dredged material before releasing the sites to State and local authorities for their use.

The cosmopolitan distribution, the ability to withstand extremes of environmental conditions, and the aggressive growth of *P. australis* make this plant a desirable species for vegetating new disposal sites containing contaminated dredged material.

1.2 Objectives and scope

The objectives of this report are to review and evaluate the literature pertaining to *Phragmites australis* with respect to its potential use in vegetating highly-contaminated dredged material and to provide CE Districts with guidelines for the establishment, maintenance and management of *P. australis* on dredged material disposal sites. Besides general biology emphasis will be placed upon:

1. Invasion into dredged material disposal sites
2. Contaminant uptake and translocation
3. Utilization
4. Management and control.

Photo 1. Dr. John W. Simmers in the middle of wealthy growing reeds, *Phragmites australis* at the dredged material confined disposal facility, Times Beach, Buffalo, N.Y. Courtesy Joop M. Marquenie.

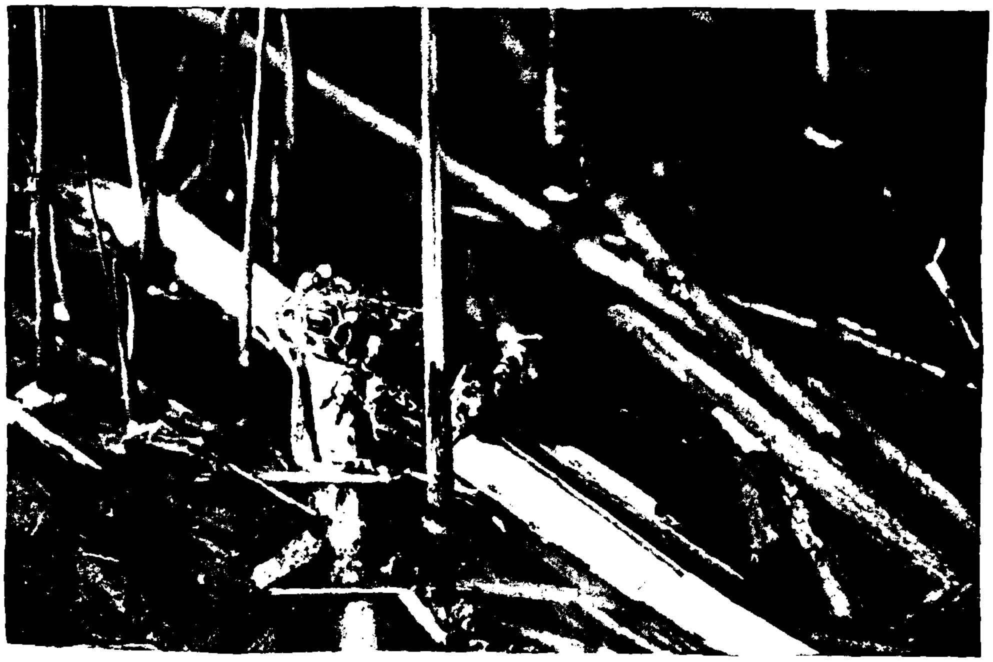

Photo 2. Reed lands used by amphibians for breeding. Times Beach, Buffalo N.Y., same location as photo 1, but now in early spring. *Courtesy Joop M. Marquenie.*

Chapter 2

General biology

2.1 Taxonomy and nomenclature

Clayton (1967) recognized three species of *Phragmites*; *P. communis* Trin., of both hemispheres; *P. karka* (Retz.) Trin. ex Steud., from Asia, Africa and Australia; and *P. mauritanus* from the tropics of Africa. Yim (1975) listed two additional species, with unspecified authors, *P. prosturatus* and *P. longivalvis* from central Korea. Clayton (1968) suggested that the name *P. communis* Trin. is a synonym of *P. australis* (Cav.) Trin. ex Steud., erected in 1799, and that *P. australis* should take precedence. Haslam (1970b, 1972) recommended careful comparison of both European and Australian plants and that long-term transplant studies should be conducted before adoption of a new name, or establishment of *P. australis* as an additional valid species. However the U.S. National Herbarium has accepted *P. australis* as the proper name of this grass (personal communication, Dr. Thomas R. Soderstrom, Department of Botany, Smithonian Institution, August 1977). The full synonymy of *P. australis* (Cav.) Trin. ex Steud. 1799 from Hitchcock (1950) and Clayton (1968) is listed below:

Arundo phragmites L. 1753
Arundo vulgaris Lam. 1778
Arundo palustris Salisb. 1796
Phragmites communis Trin. 1820
Reimaria diffusa Spreng. 1822
Cynodon phragmites Raspail 1825
Phragmites vulgaris Crep. 1866
Phragmites berlandieri Fourn. 1877
Phragmites phragmites Karst 1883
Trichoon phragmites Rendle 1899
Oxyanthe phragmites Nieuwl. 1914
Phragmites communis var. *berlandieri* Fern. 1925
Phragmites maximum var. *berlandieri* Moldenke 1936

2.2 Morphology

The following description of *Phragmites australis* is given after Hubbard (1968) (Fig. 1).:

> "A robust perennial, 1.5-3 m high, spreading by stout creeping rhizomes and stolons. Culms erect, rigid, stout, closely sheathed, many-noded, usually unbranched, smooth. Leaves greyish-green, smooth; sheaths rounded on the back, overlapping; ligule (LI,x2) a dense fringe of short hairs; blades contracted at the base, long-tapering to a very fine curved or flexuous tip, flat, 20-60 cm (or more) long, 10-30 mm wide, tough, closely nerved, ultimately falling from the sheaths. Panicles erect or finally nodding, 15-40 cm long, loose to dense, soft, purplish or brownish, much-branched, with smooth or nearly smooth branches, hairy at intervals; pedicels short. Spikelets (S,x3) lanceolate, at length widely gaping, 10-16 mm long, 2-6 flowered, with the lowest floret male and the others bisexual, the hairy axis breaking up at maturity beneath each fertile lemma (F). Glumes (G_1,G_2,x4) persistent, membranous, smooth, 3-5-nerved, the lower half to two-thirds the length of the upper, the upper about half the length of the lowest lemma. Lowest lemma (LL,x4) narrowly lanceolate, pointed 9-13 mm long, membranous, mostly 3-nerved, smooth. Fertile lemmas (F,L_2,x4) narrower, more finely pointed, thinner, 1-3-nerved, surrounded by white silky hairs (F) up to 9 mm long from the spikelet-axis. Paleas (P,x4) 3-4 mm long. Anthers (FL,x6) 1.5-2 mm long. Grain (CE,CH,x12) enclosed by the thin lemma and palea."

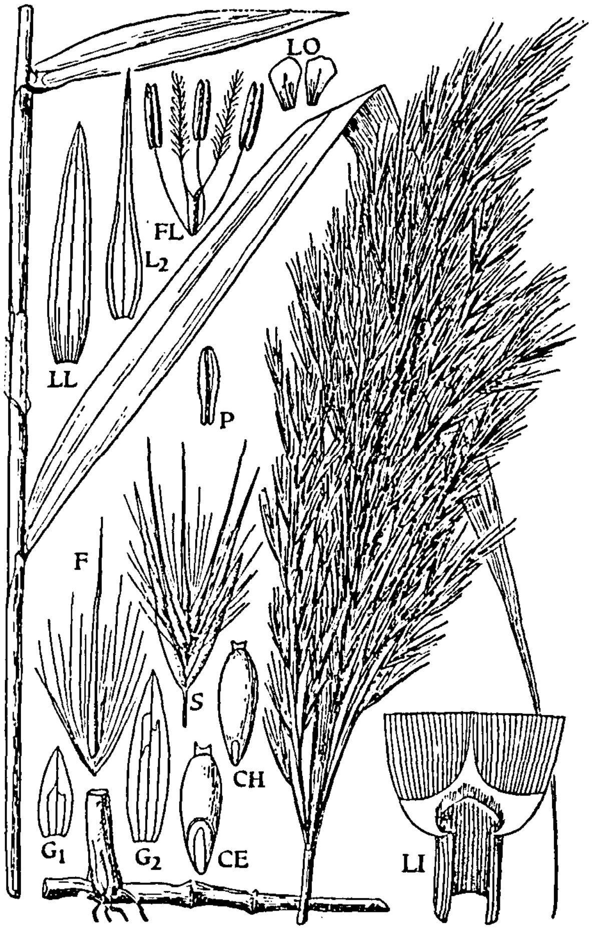

Fig. 1. *Phragmites australis*, after Hubbard 1968.
For explanation see text.

P. australis is a variable species (Haslam 1972, Van der Toorn 1972). Haslam (1972) has described the growth morphology in detail:

> "Normally in a sparse stand a bud near the base of the last year's vertical rhizome develops, in late summer, into a horizontal rhizome growing in a similar direction to its predecessor. After extending for about 1 m, the rhizome apex turns upwards, and remains dormant near the surface until spring, when it grows into an aerial shoot, which may flower. .... The cycle is then repeated. .... Rhizomes normally live for 3-6 years. .... Any lateral bud can potentially develop into a horizontal or vertical rhizome, or an aerial stem. ...."

The overwintering buds from the horizontal rhizomes are generally wider than those formed in spring and produce longer vertical rhizomes (Haslam 1969c). Horizontal rhizomes bear only one or two roots per node. Roots from upper parts of the vertical rhizomes will branch and form dense mats (Haslam 1972). The normal depth range for horizontal rhizomes is 0.4-1 m (Haslam 1972). Also depths down to 2 m are noted by Zonneveld (1959) and Hürliman (1951).

All aerial shoots are annual, except in frost-free regions where they may persist for 2 years. The tall robust shoots from wider buds are most inclined to flower. Smaller stems may bear small inflorescences, which emerge only if conditions are suitable (Haslam 1972). Inflorescences emerge in late July to early August in Britain; flowering occurs until late August or early September with the fruits maturing by November. Cross pollination takes place by wind. Seed dispersal is also normally by wind (Haslam 1972). In the United States and Canada, flowering generally occurs between July and September.

2.2.1 Chromosomes

The chromosome number of *P. australis* is generally accepted to be 2n=48, where it concerns a tetraploid form (Van der Toorn 1972). Counts different from 48 in a karyological survey of 56 populations (Gorenflot et al. 1972) lie close to this value. Occasionally, hexaploid or octoploid clones are found (Björk 1967, Gorenflot et al. 1972). The relationships of various karyotypes of European varieties of *P.australis* have been described by Raicu et al. (1972).

2.3 Geografic distribution

Phragmites australis is found abundantly in temperate climates at low altitutes around the fringes of marshes, particularly upland of salt marshes and where salt marshes grade into freshwater wetlands. It has a circumpolar distribution. A map of the geografic distribution of *Phragmites australis* after Van der Toorn (1972) is given in Fig. 2. *P. australis* is found in all coastal states of the United States and has been reported to occur in nearly all states in the continental United States.

2.4 Physiological requirements

2.4.1 Substrate

Stands of *P. australis* are found in soil textures varying from gravel to silt and clay (Van der Toorn 1972, Boorman 1981). But they grow better in a fine texture (Haslam 1973). The organic content may vary from 1-97% (Misra 1938, Haslam 1972). They often occur in peat soils (Van der Toorn 1972, Boorman 1981). However, in some environments the contact with the soil is unnecessary, as the reed forms thick mats (0.5-1.2 m) floating on the water surface (Szczepanski 1978). *Phragmites australis* grows at a soil or water surface pH ranging from 3.6 to 8.6, but the more robust stands appear within a range of 5.5 to 7.5 (Haslam 1972). Various pH ranges reported in the literature are presented below (Table 1). *Phragmites* shows a clear preference for mesotrophic or eutrophic environments.

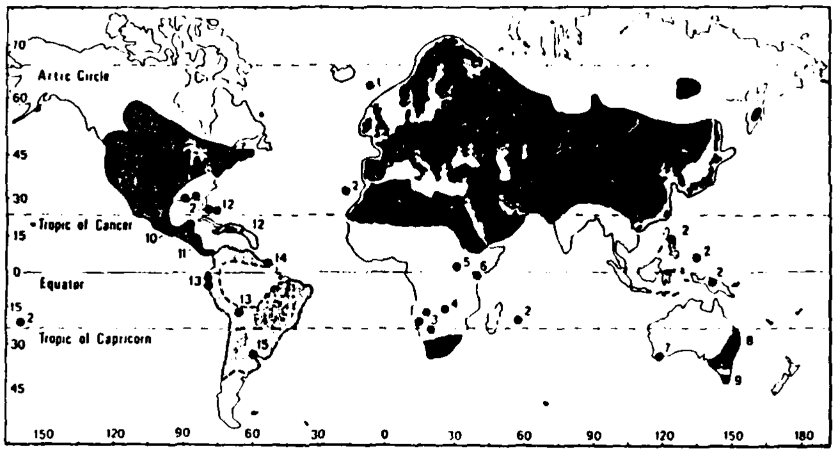

Fig. 2. Geographic distribution of *Phragmites australis*, after Van der Toorn 1972.

Distribution fairly well known: broken line indicates that the exact boundary of the distribution area is not known

Probably occurring; distribution not well known

Isolated finds

Numbers refer tot the following literature:

1 Ostenfeld and Grøntved, 1934
2 Hultén, 1962
3 Launert, 1970
4 Gordon-Gray and Ward, 1971
5 Conert, 1961
6 Clayton, 1970
7 Gardner, 1952
8 Burbridge, 1966, 1968, 1970
9 Townrow, 1969
10 Hitchcock, 1913
11 Hitchcock, 1930
12 Hitchcock, 1936
13 Hitchcock, 1927
14 Amshoff and Henrard, 1948
15 Cabrera, 1953

TABLE 1. pH Ranges reported in literature.

AREA	pH RANGE Water	Soil	Unspecified	REFERENCE
Norfolk, England			7.2-7.3	Godwin and Turner (1933)
New Forest, England	5.0-5.4	4.9-5.3		Newbould and Gorham (1956)
Various English Lakes			5.3-7.3	Misra (1938)
Scotland			4.6-6.0	Gorham and Pearsall (1956a)
Kalenberg, The Netherlands		5.9-7.4		Van der Toorn (1972)
S. Sweden, several sites	5.3-8.0	4.5-9.3		Bjork (1967)
Western Utah			8.2-9.2	Bolen (1964)
Point Pelee, Ontario	6.8-7.5	6.9-8.1		Bayly and O'Neill (1972)

2.4.2 Water level

Phragmites usually grows with the water level, where the oxygen supply to the roots is low and so the redox potential is low. In order to overcome a long-term anaerobic condition *Phragmites* has an aerenchymatous system which can transport atmospheric oxygen to the roots. In temperate climates the plant can occur as much as 2 m above and about 1 m below the permanent water level (Haslam 1970c). In warmer climates, *P. australis* will occur at greater depths (In Uganda as deep as 4 m; Haslam 1972). In Britain, the maximum depth of approximately 1.5 is associated with mineral-rich water. Because few competitors exist in deep water, an insufficient oxygen influx (Yamasaki 1984) and nutrient status appear to control the lower boundary (Haslam 1970c, 1971b).

At the dry end of the range, *P. australis* usually occurs as a restricted population. Competition, nutrient status, and water level are controling factors. Rhizomes can reach almost 2 m below the soil surface with roots penetrating even deeper, allowing the plant to reach low soil layers (Haslam 1970c). Water level effects bud width and consequently shoot height. Buds in unflooded soil tend to be high (slightly above and to 13 cm below the soil surface) and narrow, while those in flooded areas are wider and deeper (Haslam 1970c).

Under flooded conditions *P. australis* tends to have the highest production and the largest development of new rhizomes (Yamasaki 1981). This is in contradiction with the findings of Rezk and Edany (1979). They found tallest shoots at a water level of 0.1 m below soil surface. Shoot density was not considered. For effects of drainage and drying of the soil on an established dense reed vegetation , see "succession" and "management".

2.4.3 Temperature

Phragmites australis is found in temperate and warm climates. It is not found in artic regions and on high altitudes. An increase in height of aerial shoots is noted with decreasing latitude and altitude as well as warm summers (Haslam 1972). Young shoots grow fastest at approximately 25 ^{o}C (Haslam 1971c, 1973). Frosts or cold will increase shoot density, crop weight, and pre-emergence period (Haslam 1969b, 1972) and will stimulate bud development, but in turn will decrease stem height and diameter. Severe frosts of -14 ^{o}C or below may kill up to 100 % of the shoots. Buds cannot survive more than three consecutive days of frozen soil (Haslam 1972). A high water level tends to protect new shoots from frost in cooler climates (Haslam 1970c). Haslam (1972) found recovery from frost damage may be very slow.

Haslam (1972) stated that a hot summer can increase reed height up to 0.5 m. The increased length occurs at the internodes. Generally, short-duration of hot and cold spells have little effect on the overall growth-rate (Haslam 1969b). Seedling establishment, bud emergence, and the timing of the growth cycle are the areas of possible temperature related ecotypic variation (Haslam 1975).

2.4.4 Light

The absence of light inhibits the seedling growth rate of *P.australis* (Haslam 1971c, 1972, 1973). Insufficient light will cause the development of flaccid leaves and an increase in blade weight. Biotopes normally producing a pronounced ribbing of the blades will not manifest this character (Haslam 1971c, 1972, 1973). Shading will tend to decrease the size of the stem and cause the inflorescence to be less dense (Lambert 1946). Shaded shoots tend to be narrower with longer blades (Haslam 1971c).

An evaluation of the effects of variation in the amount of shoot area exposed to light, amount of light available, and water depth on the rate of transpiration in *P.australis* was reported by Burian (1971, 1973). Among the environmental variants were temperature and seasonal fluctuations in the amount of radiant energy received. The correlation between the amount of radiant energy and apparent photosynthesis as indicated by the amount of CO_2 used per day varied according to temperature. Ondok (1973a) developed a model of extinction of PhAR (photosynthetically active radiation) in a *Phragmites* stand. The model is based on the "relative volume of shading" (Vr) defined by the size of the plant aerial organs and their spatial distribution. In further considerations by Ondok (1973b), SLI (sunlit area index) and its daily course were correlated for four dates in the growing season, as was the distribution of irradiance by PhAR on the sunlit foliage area (El). SLI and distribution of El depend on changes in canopy shape and vary during the growing season. The sharp difference observed in El values between high and low sun elevation in spring and fall seems to be less favorable for photosynthetic activity than the more constant values of summer.

The photosynthesis of a single shoot of *P.australis* was examined by Walker and Waygood (1968). A plastic bag was fastened over a plant 1.64 m high with 15 internodes, 14 leaves and an unrolled terminal leaf. CO_2 was administered for one hour on a clear day and subsequently extracted from the plant parts. The greatest concentration of CO_2 was found in the central leaves. The leaf sheaths and internodes fixed only 8% of the total. Leaf area was the only index useful in determining photosynthesis, and an average of 6.1 +/- 0.62 (S.D.) mg $CO_2.cm^{-2}.hr^{-1}$ was determined. The rate of photosynthesis increased from the lowest to the uppermost leaves, a finding supported by Dykyjova et al. (1970).

Oxygen content of rhizomes, stems, and leaves was studied by Krasovskii and Chashckukhin (1974). The oxygen content of the rhizomes in flooded ground, increased from 4-9 % in spring to 15-19 % in midsummer. Oxygen content of stems varied from 19-22 % and of leaves from 12-23 %. It was presumed that oxygen resulting from photosynthesis was transferred to the rhizomes.

2.4.5 Evapotranspiration

The transpiration rate for *P. australis* is considered high, varying with the ecotype of the plant and temperature. Transpiration occurs between May and September in Great Britain with peak periods in July and August (Haslam 1970c). In Manitoba, Canada, Phillips (1976) found the peak period of transpiration also occurred in July. Transpiration accounted for 75-90% of evapotranspiration, depending on the site. Gravimetric measurements of transpiration in *Phragmites* have been made by several Central European plant physiologists. A summary of results of daily values of evapotranspiration are presented below (Table 2).

TABLE 2. Daily values of evapotranspiration (in mm)

EVAPO-TRANSPIRATION	CIRCUMSTANCES	REFERENCE
12.2 13.7	single leaves,July	Tuschl (1970)
7.7-7.9	whole shoots,littoral stand	Kvet (1973b)
6.9-11.4	whole shoots,limnosal stand	Rychnovska and Smid (1973)
5.6	vigorously growing, 1 June	Smid (1975)
6.9	id. 27 June	id.
5.5	id. 11 August	id.
1.4	id. 5 October	id.

Evapotranspiration of vigorous *P. australis* stands was considered by Vostkova (1975) to remove a large amount of subsurface water and effect the hydrological condition of the sand deserts of the Northern Aral region of the U.S.S.R. In the Netherlands (Van der Toorn 1982) and Japan (Kamio 1982), *Phragmites* is often introduced in polders after initial reclamation. The active transpiration of *P. australis* plants can reduce soil water in the lower layers of the ground and so help to reduce water the content of muddy soil.

Khashes and Bobro (1971) found daily transpiration characterized by a single peak at 12.00 - 13.00 h. They suggested that the morning transpiration value is correlated with air temperature and deficit of saturation while the afternoon drop in transpiration is conditioned by the physiological state of the leaves.

Additional factors regulate the evapotranspiration rate. Krolikowska (1971) examined *Phragmites* at terrestrial and aquatic sites around Midolajski Lake, Poland, and found evapotranspiration increases in proportion to increases in fresh weight, air temperature, and solar radiation. As expected a rise in relative humidity decreased transpiration, as did inflorescence formation. The intensity of transpiration rose rapidly in the morning and decreased in the afternoon. The younger leaves of the upper portion of the aerial shoots transpired more than the lower (older) leaves. Pazourek (1973) found a stomatal gradient did exist from basal to apical leaves.

2.4.6 Nutrient uptake

As mentioned above, *Phragmites australis* can grow in an exceptionally wide range of soil and water chemistry. It can be limited by different nutrients, depending on the nutrient status of the area concerned. *Phragmites* grows potentially well in mesotrophic and eutrophic habitats. As the nutrient concentration is usually higher in fine-grained substrates than in coarse-grained, *Phragmites* grows better in the former one. In eutrophic habitats *Phragmites* is frequently limited by competition (Haslam 1973). Haslam (1973) learned that nutrient uptake is mainly from the upper 0.5 m of the soil, by the branched horizontal roots of the upper rhizomes. But, the hydropotes of the submerged above-ground part of the aerial shoot may also play a large role in nutrient uptake, even many times higher than the uptake by the underground roots (Luther 1983).

A large number of measurements have been carried out on the nutrient status of soil and water in *Phragmites* stands and on the nutrient concentration in the plant tissue. In order to get an impression of the substrate characteristics of *Phragmites*, in this review a summary will be given of these data in natural stands. Also the effect of fertilizers will be mentioned and the effect of the season.

2.4.6.1 Nitrogen

Nitrogen (N) is absorbed by plant roots in the form of nitrate or ammonium ions.

Banoub(1975) measured the differences in water chemistry in the Gnadensee without and within a *Phragmites* stand. The pH decreases during the growing season as one penetrates deeper into the reeds as does the concentration of total inorganic N, of NO_2-N and especially of NO_3-N, whereas the NH_4-N concentration increases. Table 3 gives the concentrations of different forms of N in the surface water in a reed stand. Table 4 gives the N concentration in the soil.

TABLE 3. N concentration (in ug.l^{-1}) in the surface water in a *Phragmites* stand.

	MINIMUM	MAXIMUM	AVERAGE	REFERENCE
NO_2-N	1.0	69.0	7.8	(a)
	traces	23		(b)
NO_3-N	40.0	250.0	131.3	(a)
	90	621		(b)
			420	(c)
	25	4990		(d)
	73	1126		(d)
NH_4-N	91.0	450.0	177.0	(a)
	15	77		(b)
			540	(c)
	350	1500		(d)
	397	793		(d)
inorg-N	249.0	531.0	321.0	(a)
N total	10	3620		(d)

ref.a: Banoub 1975; ref.b: Kaul 1984 (8 sites, during 2 years; ref.c: Ulehlova et al. 1973 (aver. over 1 year, 5 sites; recalculated); ref.d: Dykyjova and Kvet 1978.

TABLE 4. N concentration (in $mg.kg^{-1}$ dry weight) in soil, sediment and sapropel in a *Phragmites* stand.

	SOIL	SAPROPEL	REFERENCE
NO_3-N	3.4	9.0	(c)
	16 - 181	12 - 17	(h)
(NO_3+NO_2)-N	0.1 - 5.1		(e)
NH_4-N	36	69	(c)
	26 - 605		(e)
	51 - 238	30 - 73	(h)
inorg.N (extractable)	3.3 - 39.6		(f)
total N	1800 - 5300		(e)
	100 - 23800		(f)
	5040 - 27200		(b)
(in $g.l^{-1}$)	1.36 - 2.1		(g)

ref.b: Kaul 1984 (during 2 years, 8 sites); ref.c: Ulehlova et al. 1973 (aver. over 2 years, 5 sites); ref.e: Boorman and Fuller 1981; ref.f: Ho 1981b; ref.g: Schlott and Malicky 1984; ref.h: Dykyjova and Kvet 1978 (sapropel: 0-25 cm, sediment 25-40 cm).

The variation of nitrogen concentration in water is a seasonal effect, whereas the variation in soil or sapropel is more a spatial one (Dykyjova and Kvet 1978). Dykyjova (1979) compared the N concentration in the soil with that of the plant (Table 5).

TABLE 5. N concentration in soil and plant tissue in $mg.kg^{-1}$ dry weight.

	SOIL	PLANT	CONCENTR. FACTOR
sand	0.7	1.53	2.18
deep layer of sapropel	1.7	1.91	1.12

Table 6 gives a survey of several values of N concentrations in different organs of *Phragmites*.

TABLE 6. Range of N concentrations in tissues of *Phragmites australis* in % dry weight.

ORGAN				REFERENCE
rhizomes	0.689	–	1.417	(f)
	0.55		(0.59)	(m)
	1.06	–	1.53	(n)
	0.919			(c)
roots	0.968	–	1.85	(f)
	0.85		(0.86)	(m)
	o.992			(c)
roothairs	1.23		(1.09)	(m)
belowground organs	1.17			(q)
stems	0.939	–	1.601	(f)
	1.12	–	2.34	(i+j)
	0.83		(0.74)	(m)
	1.18	–	2.93	(n)
	0.12	–	0.53	(r)
young	0.992			(c)
ripe	0.808			(c)
dying off	0.772			(c)
leaves	2.477	–	3.473	(f)
	1.3	–	2.7	(k)
	3.13		(2.42)	(m)
	3.35	–	5.10	(i+j)
	2.59	–	3.43	(r)
young	4.41			(c)
ripe	3.16			(c)
dying off	3.013			(c)
stems+leaves	2.1	–	3.35	(e)
	1.233			(l)
	0.64	–	2.61	(g)
	0.79	–	2.88	(o)
	1.11	–	1.96	(p)
	1.36			(q)
	1.00	–	2.77	(j)
panicle	1.938	–	3.420	(f)

ref.c: Ulehlova et al. 1973; ref.e: Boorman and Fuller 1981; ref.f: Ho 1981b; ref.g: Schlott and Malicky 1984; ref.i: Kvet 1973; ref.j: Dykyjova 1979; ref.k: Allen and Pearsall 1963; ref.l: Auclair 1979; ref.m: Kovacs et al. 1978 (the data between brackets are from 1 year later) ref.n: Van der Linden 1980 (variation over 1 year); ref.o: Best 1981 (variation over 1 year); ref.p: Van der Toorn 1972 (min. and max. of 29 sites in August); ref.q: Roman and Daiber 1984 (mean annual value of 8 and 15 samples resp); ref.r: Sieghardt and Maier 1985 (min. and max. of season)

The N concentration in plant tissue is highest in the growing season. The % N decreases in leaves and stem from 2.61 in June to 0.64 in January (Schlott and Malicky 1984) and from 2.77 in May to 1.00 in October (Dykyjova 1979). The N content of the shoots decreases after August, whereas the N content of the rhizomes increases. This shows the internal retranslocation of N in the plant. Also the appearance of the new shoot biomass in the first half of the growing season coincides with a decrease of the N content of the rhizomes (Van der Linden 1980). In relation to this the N concentration decreases with age (Ulehlova et al. 1973).

Allen and Pearsall (1963) found that shoot production is related with the quota of N per leaf (Allen and Pearsall 1963).

2.4.6.2 Phosphorus

Another important macronutrient is phosphorus (P). Table 7 gives some data of the phosphate concentration of the surface water in a reed stand. The concentration of P in water can fluctuate heavily during the season (Bayly and O'Neill 1972). Like in nitrogen Banoub (1975) also found higher P concentrations inside the reed stand than outside.

Table 8. gives some data about the P status in the soil of a reed stand. The data of the soil extract or available P can differ according to the extraction method used.

TABLE 7. Range of concentration of P (in $mg.l^{-1}$) in the surface water in a reed stand.

				REFERENCE
TP	0.15	-	0.79	(a)
	0.159	-	0.552	(b)
	0.87			(d)
	0.02	-	1.0	(e)
	0.024	-	0.240	(c)
DIP	0.029	-	0.046	(b)
	0.003	-	0.084	(c)
DOP	0.124	-	0.518	(b)
	0.010	-	0.084	(c)
PIP	0.001	-	0.010	(c)
POP	0.011	-	0.072	(c)

TP (total phosphate-phosphorus); DIP (dissolved inorganic phosphate-phosphorus); DOP (dissolved organic phosphate-phosphorus); PIP (particulate inorganic phosphate-phosphorus); POP (particulate organic phosphate-phosphorus)

ref.a: Bayly and O'Neill 1972 (min and max during the season); ref.b: Kaul 1984 (8 sites, during 2 years); ref.c: Banoub 1975; ref.d: Ulehlova et al. 1973; ref.e: Ho 1981 (min and max of 3 sites).

TABLE 8. Range of concentrations of P in soil in a reed stand in $mg.kg^{-1}$ dry weight.

TOTAL P	SOIL EXTRACT/ AVAILABLE P	sapropel EXTRACT	REFERENCE
240 - 800			(a)
540 - 2320	20 - 130		(b)
	8.2	11.7	(d)
	51 - 380		(f)
	0.3 - 33.1		(e)

ref.a: Bayly and O'Neill 1972 (min. and max. during the season); ref.b: Kaul 1984 (8 sites, during 2 years; ref.d: Ulehlova et al. 1973 (mean value of 5 sites over 2 years, monthly); ref.e: Ho 1981 (min. and max. of 4 sites); ref.f: Boorman and Fuller 1981 (min. and max. of 6 sites).

Bayly and O'Neill (1972) found an increase in the total P concentration in the soil from May to August.

The concentrations of P in different organs of *Phragmites* is summarized in Table 9.

TABLE 9. Range of concentrations of P in *Phragmites australis* in % dry weight.

ORGAN		REFERENCE
rhizome	0.06 (0.08)	(h)
	0.406	(d)
	0.133 - 0.238	(e)
root	0.09 (0.10)	(h)
	0.309	(d)
	0.171 - 0.541	(e)
roothair	0.10 (0.14)	(h)
stem	0.07 (0.08)	(h)
	0.084 - 0.185	(i + l)
	0.164 - 0.237	(e)
	0.04 - 0.13	(p)
young plants	0.293	(d)
ripe plants	0.172	(d)
dying off plants	0.180	(d)
leaves	0.13 (0.15)	(h)
	0.152 - 0.240	(i)
	0.03 - 0.17	(j)
	0.21 - 0.28	(e)
	0.14 - 0.22	(p)
young plants	0.353	(d)
ripe plants	0.309	(d)
dying off plants	0.231	(d)
	0.125 - 0.240	(l)
stem + leaves	0.15 - 0.79	(a)
	0.1515	(q)
	0.245 - 0.415	(f)
	0.033 - 0.312	(k)
	0.17 - 0.48	(l)
	0.20 - 0.36	(m)
	0.029 - 0.149 (mean: 1.05+_0.26)	(n)
	0.071 - 0.194	(o)
nutrient poor	0.19	(l)
nutrient rich	0.28	(l)
panicle	0.299 - 0.496	(e)

ref.a: Bayly and O'Neill 1972; ref.b: Kaul 1984 (8 sites, during 2 years; ref.d: Ulehlova et al. 1973; ref.e: Ho 1981 (min. and max. of 3 sites); ref.f: Boorman and Fuller 1981 (min. and max. values of 6 sites); ref.g: Auclair 1979; ref.h: Kovacs et al. 1978 (values between brackets are from 1 year later); ref.i: Kvet 1973a (min. and max. values of 14 sites); ref.j: Allen and Pearsall 1963 (min. and max. values of 11 sites); ref.k: Schlott and Malicky 1984; ref.l: Dykyjova 1979 (min and max of 14 sites at the peak of the growing season; the poor soil represents a sandy soil, the rich soil a deep layer of sapropel); ref.m: Best et al. 1981; ref.n: Kufel and Kufel 1980 (min., max. and mean of 37 sites); ref.o: Van der Toorn 1972 (min. and max. of 29 sites in August); ref.p: Sieghardt and Maier 1985 (min. and max. of season).

Bayly and O'Neill (1972), Dykyjova (1979), Best et al. (1981) and Schlott and Malicky (1984), found the highest P levels in the shoots in spring, which decrease to the low levels in autumn and winter.

2.4.6.3 Potassium

Potassium (K) levels in the surface water and soil in a reed stand are given in Table 10 and Table 11.

TABLE 10. Range of K levels (in $mg.l^{-1}$) in the surface water in a reed stand.

	REFERENCE
5.6 - 13.0	(a)
0.71 - 2.52	(b)
0.2 - 10	(c)
30.33	(d)
1.21 - 7.89	(e)

ref.a: Bayly and O'Neill 1972; ref.b: Kaul 1984 (8 sites, during 2 years); ref.c: Allen and Pearsall 1963 (min. and max. of 11 sites); ref.d: Ulehlova et al. 1973 (5 sites, during 2 years); ref.e: Ho 1981b (min. and max. of 3 sites).

Bayly and O'Neill (1972) found an increase in the K concentration from May to August.

TABLE 11. The range of K concentrations (in $mg.kg^{-1}$) in the soil in a *Phragmites* stand.

	TOTAL K	EXTRACT (1N ammonium acetate)	REFERENCE
		50 - 280	(a)
	4800 - 21200		(b)
bottom	224		(d)
sapropel	335		(d)
		19.7 - 570	(e)

ref.a: Bayly and O'Neill 1972 (variation during the year); ref.b: Kaul 1984 (8 sites, during 2 years); ref.d: Ulehlova et al. 1973 (5 sites during 2 years); ref.e: Ho 1981 (min. and max. values of 4 sites).

TABLE 12. Range of K concentrations in different organs of *Phragmites australis* in % dry weight.

ORGAN		REFERENCE
rhizome	0.95 (1.24)	(g)
	0.709	(d)
	1.325 - 1.878	(e)
root	0.459	(d)
	0.64 (0.63)	(g)
	0.570 - 0.842	(e)
roothair	0.44 (0.95)	(g)
stem	0.89 (1.16)	(g)
	0.55 - 1.39	(h)
	1.821 - 2.223	(e)
	0.61 - 1.49	(j)
	0.24 - 0.92	(l)
young plants	1.123	(d)
ripe plants	0.509	(d)
dying off plants	0.325	(d)
leaves	1.13 (1.22)	(g)
	1.21 - 2.07	(h)
	0.07 - 0.85	(c)
	1.363 - 1.720	(e)
	1.21 - 2.07	(j)
	0.85 - 2.14	(l)
young plants	1.060	(d)
ripe plants	0.840	(d)
dying off plants	0.499	(d)
stem + leaves	<0.01 - 1.95	(a)
	1.392	(f)
	2.0 - 3.25	(i)
	0.55 - 2.76	(j)
	0.373 - 1.653	(k)
poor soil	1.08	(j)
rich soil	1.74	(j)
panicle	1.247 - 1.740	(e)

ref.a: Bayly and O'Neill 1972; ref.b: Kaul 1984; ref.c: Allen and Pearsall 1963 (min. and max. of 11 sites); ref.d: Ulehlova et al. 1973; ref.e: Ho 1981b (min. and max. of 3 sites); ref.f: Auclair 1979; ref.g: Kovacs et al. 1978 (the data between brackets are from 1 year later); ref.h: Kvet 1973a (min. and max. of 14 sites); ref.i: Boorman and Fuller 1981 (min. and max. of 6 sites); ref.j: Dykyjova 1979 (min. and max. of 14 sites at the peak of the growing season; the poor soil represents a sandy soil, the rich soil a deep layer of sapropel); ref.k: Van der Toorn 1972 (min. and max. of 29 sites in August). ref.l: Sieghardt and Maier 1985 (min. and max. of season).

Bayly and O'Neill (1972) and Dykyjova (1979) measured a decrease from a high K content in May to a very low K concentration in October.

2.4.6.4 Sodium

As *Phragmites* occurs on inland sites as well as on the upper edges of salt marshes, there will be a large variation in the sodium (Na) concentration of the soil and surface water. Table 13 and 14 give the ranges of the substrate characteristics for Na in which *Phragmites* grows.

TABLE 13. Ranges of the concentration of Na (in $mg.l^{-1}$) in the surface water in *Phragmites* stands.

	REFERENCE
3.3 - 7.9	(a)
8 - 15	(b)
66.7	(c)
5.90 - 38.64	(d)

ref.a: Bayly and O'Neill 1972 (during the season); ref.b: Kaul 1984; ref.c: Ulehlova et al. 1973 (mean value of 5 sites during 2 years) ref.d: Ho 1981 (min. and max. of 3 sites).

TABLE 14. Range of concentrations of Na in the soil (in $mg.kg^{-1}$ dry weight) in *Phragmites* stands.

	TOTAL Na	EXTRACT (1N ammonium acetate)	REFERENCE
	420 - 1460		(b)
		43.0 - 438.9	(d)
bottom soil	95		(c)
sapropel	159		(c)

ref.b:kaul 1984; ref.c: Ulehlova et al. 1973 (mean value of 5 sites during 2 years); ref.d: Ho 1981 (min. and max. of 4 sites).

Table 15 gives the Na concentration in the different organs of *Phragmites*.

TABLE 15. Ranges of Na concentration in *Phragmites australis* tissue in % dry weight.

ORGANS		REFERENCE
rhizome	0.08 (0.11)	(e)
	0.184	(c)
	0.123 - 0.198	(d)
root	0.19 (0.24)	(e)
	0.206	(c)
	0.245 - 0.354	(d)
roothair	0.14 (0.32)	(e)
stems	0.05 (0.06)	(e)
	0.045 - 0.130	(f)
	0.082 - 0.105	(d)
	0.044 - 0.129	(g)
young plants	0.044	(c)
ripe plants	0.041	(c)
dying off plants	0.063	(c)
leaves	0.02 (0.04)	(e)
	0.035 - 0.08	(f)
	0.08 - 0.65	(h)
	0.032 - 0.049	(d)
	0.035 - 0.080	(g)
young plants	0.031	(c)
ripe plants	0.031	(c)
dying off plants	0.027	(c)
stems + leaves	0.02 - 0.052	(a)
	0.071	(i)
	0.056 - 0.270	(j)
poor soil	0.03	(g)
rich soil	0.05	(g)
panicle	0.056 - 0.089	(d)

ref.a: Bayly and O'Neill 1972 (fluctuations throughout the growing season); ref.b: Kaul 1984; ref.c: Ulehlova et al. 1973; ref.d: Ho 1981 (min. and max. of 3 sites); ref.e: Kovacs et al. 1978 (data between brackets are from 1 year later); ref.f: Kvet 1973a (min. and max. of 14 sites); ref.g: Dykyjova 1979 (min. and max. of 14 sites at the peak of the growing season; ref.h: Allen and Pearsall 1963 (min. and max. of 11 sites); ref.i: Auclair 1979; ref.j: Van der Toorn 1972 (min. and max. of 29 sites in August).

In a peat water regime, Daniels (1975) found a good correlation between the quantity of sodium in the water and that in the aerial portion of the plant. Such a correlation was not observed with other ions in the water.

2.4.6.5 Chlorine

There are only a few data on the chlorine (Cl) concentrations in the habitat of *Phragmites*. In a fresh water habitat Banoub (1975) measured a same Cl concentration in the water of 3.1 - 9.3 mg.l^{-1} within as well as without the reed stand. Kaul (1984) found a level in the water of 9 - 12 mg.l^{-1}. However, the species shows a rather high salt tolerance. Ranwell et al. (1964) reported that *Phragmites* can tolerate up to 1.2 % chlorinity in the 10-12 cm soil layer. Juvenile plants seem to be more sensitive, having a critical limit at 0.9 mg Cl.l^{-1}, whereas adult plants show no inhibition at this concentration (Bakker et al. 1957). Haslam (1971c) discovered that plants of 10 cm high transplanted to a 2 % chloride value remained small. At a 1 % concentration, the transplants varied from small to the size of the controls. At a 0.5 % value, plants achieved a size comparable to controls. Presumably the controls were grown in fresh water.

Van der Toorn (1972) found 0.395 - 1.230 % Cl (dry weight) in the shoots of *Phragmites australis* as the range over 29 sites in August.

2.4.6.6 Calcium

The levels of calcium (Ca) concentration in the surface water (Table 16) in a reed stand can vary largely as also the pH range can be very wide.

TABLE 16. Range of Ca concentrations in the surface water in a stand of *Phragmites* in $mg.l^{-1}$.

		REFERENCE
45 - 72		(a)
29 - 62		(b)
43.0 - 75.0	(av. 53.3)	(c)
3 - 270		(d)
91.37		(e)
5.77 - 31.82		(f)

ref.a: Bayly and O'Neill 1972 (during the season); ref.b: Kaul 1984 (min. and max. of 8 sites during 2 years); ref.c: Banoub 1975; ref.d: Allen and Pearsall 1963 (min. and max. of 11 sites); ref.e: Ulehlova et al. 1973 (mean value of 5 sites, during 2 years); ref.f: Ho 1981 (min. and max. of 3 sites).

Bayly and O'Neill (1972) didn't find a trend in the Ca concentration during the growing season. Banoub (1975) measured a slightly lower Ca concentration (aver. 49.3 mg/l) out of the reed stand.

TABLE 17. Range of Ca concentrations in the soil in a stand of *Phragmites* in $mg.kg^{-1}$ dry weight.

	TOTAL Ca	EXTRACT (1N ammonium acetate)	REFERENCE
	9600 - 18900		(a)
	19500 - 39500		(b)
bottom soil	2820		(e)
sapropel	3820		(e)
		66000 - 429000	(g)
	462 - 5015		(f)

ref.a: Bayly and O'Neill 1972 (during the season); ref.b: Kaul 1984; ref.e: Ulehlova et al. 1973 (mean value of 5 sites, during 2 years); ref.g: Boorman and Fuller 1981 (min. and max. of 6 sites); ref.f: Ho 1981 (min. and max. of 4 sites).

Ca concentrations, the total as well as in the extract, can vary enormously. No trends were found during the season (Bayly and O'Neill 1972).

Ranges of Ca concentration as found in the tissues of *Phragmites* are presented in Table 18.

TABLE 18. Ranges of Ca concentrations in different organs of *Phragmites australis* in % dry weight.

ORGAN		REFERENCE
rhizomes	0.17 (0.35)	(h)
	0.386	(e)
	0.320 - 0.454	(f)
roots	0.75 (1.34)	(h)
	0.104	(e)
	0.252 - 0.468	(f)
roothair	1.39 (2.05)	(h)
stem	0.09 (0.08)	(h)
	0.062 - 0.129	(i)
	0.427 - 0.514	(f)
	0.062 - 0.156	(j)
	0.03 0.05	(n)
young plants	0.076	(e)
ripe plants	0.044	(e)
dying off plants	0.061	(e)
leaves	0.22 (0.19)	(h)
	0.245 - 0.651	(i)
	0.24 - 0.77	(d)
	0.692 - 0.973	(f)
	0.249 - 0.651	(j)
	0.16 - 0.58	(n)
young plants	0.190	(e)
ripe plants	0.319	(e)
dying off plants	0.376	(e)
stem + leaves	0.54 - 1.60	(a)
	0.278	(k)
	0.267 - 0.495	(g)
	0.14 - 0.29	(j)
	0.010 - 0.162 (mean:0.064+_0.039)	(l)
	0.128 - 0.298	(m)
poor soil	0.03	(j)
rich soil	0.29	(j)
panicle	0.420 - 0.470	(f)

ref.a: Bayly and O'Neill 1972; ref.d: Allen and Pearsall 1963 (min. and max. of 11 sites); ref.e: Ulehlova et al. 1973; ref.f: Ho 1981 (min. and max. of 3 sites); ref.g: Boorman and Fuller 1981 (min. and max. of 6 sites); ref.h: Kovacs et al.

1978 (the data between brackets are of 1 year later); ref.i: Kvet 1973a (min. and max. of 14 sites); ref.j: Dykyjova 1979 (min. and max. of 14 sites at the peak of the growing season: the poor soil represents a sandy soil, the rich soil a deep layer of sapropel); ref.k: Auclair 1979; ref.l: Kufel and Kufel 1980 (min., max. and mean value of 37 sites); ref.m: Van der Toorn 1972 (min. and max. of 29 sites in August); ref.n.: Sieghardt and Maier 1985 (min. and max. of season).

Dykyjova (1979) measured a increase in Ca content of 0.54 % to 1.60 % in the shoot from June to August. Bayly and O'Neill (1972) found an increase from 0.14 % in May to a peak in July of 0.29 % and thereafter a decrease to 0.18 % in August.

2.4.6.7 Magnesium

Data for the concentration of magnesium (Mg) in the habitat of *Phragmites* are given in Table 19 and 20.

TABLE 19. Ranges of concentrations of Mg in the surface water in *Phragmites* stands in $mg.l^{-1}$.

	REFERENCE
9.4 - 13.1	(a)
10 - 16	(b)
4.0 - 25.0 (av. 10.5)	(c)
49.23	(d)

ref.a: Bayly and O'Neill 1972 (during the season); ref.b: Kaul 1984; ref.c: Banoub 1975; ref.d: Ulehlova et al. 1973 (mean of 5 sites, during 2 years).

Bayly and O'Neill (1972) found a slight increase in the Mg concentration in the water from May to July. Banoub (1975) found the same Mg levels within and outside of the reed stand.

TABLE 20. Ranges of Mg concentrations in the soil in a *Phragmites* stand in $mg.kg^{-1}$ dry weight.

	TOTAL Mg	EXTRACT (1N ammonium acetate)	REFERENCE
		360 - 1540	(a)
	4700 - 7900		(b)
bottom soil	600		(d)
sapropel	592		(d)
	48.1 - 634.8		(e)

ref.a: Bayly and O'Neill 1972 (during the season); ref.b: Kaul 1984; ref.d: Ulehlova et al. 1973 (mean of 5 sites, during 2 years); ref.e: Ho 1981 (min. and max. of 4 sites).

Bayly and O'Neill (1972) found a minimum in the extractable Mg concentration in the soil by the end of July.

The Mg concentration in the plant tissue gives the following picture (Table 21).

Bayly and O'Neill (1972) measured a decrease in the Mg concentration in the shoot from 0.86 - 0.97 % to 0.46 - 0.73 % from May to August. Over the same season (to October) Dykyjova (1979) found a decrease from 0.14 to 0.08 %. On the contrary Wallentinus (1973) reported that Mg content in the leaves is highest at the termination of the growing season.

TABLE 21. Ranges of Mg concentrations in the different organs of *Phragmites australis* in % dry weight.

ORGAN		REFERENCE
rhizomes	0.20 (0.12)	(g)
	0.401	(d)
	0.108 - 0.136	(e)
roots	0.47 (0.30)	(g)
	0.34	(d)
	0.134 - 0.300	(e)
roothair	0.45 (0.30)	(g)
stem	0.13 (0.06)	(g)
	0.030 - 0.060	(h)
	0.158 - 0.194	(e)
	0.028 - 0.060	(j)
	0.05 - 0.12	(l)
young plants	0.077	(d)
ripe plants	0.038	(d)
dying off plants	0.0690	(d)
leaves	0.33 (0.20)	(g)
	0.120 - 0.209	(h)
	0.15 - 0.41	(i)
	0.428 - 0.486	(e)
	0.118 - 0.205	(j)
	0.15 - 0.34	(l)
young plants	0.216	(d)
ripe plants	0.270	(d)
dying off plants	0.231	(d)
stem + leaves	0.46 - 0.97	(a)
	0.067	(f)
	0.08 - 0.14	(j)
	0.058 - 0.152	(k)
poor soil	0.08	(j)
rich soil	0.17	(j)
panicle	0.302 - 0.342	(e)

ref.a: Bayly and O'Neill 1972 (during the season); ref.d: Ulehlova et al. 1973; ref.e: Ho 1981 (min. and max. of 3 sites); ref.f: Auclair 1979; ref.g: Kovacs et al. 1978 (the data between brackets are from 1 year later); ref.h: Kvet 1973a (min. and max. of 14 sites); ref.i: Allen and Pearsall 1963 (min. and max. of 11 sites); ref.j: Dykyjova 1979 (min. and max. of 14 sites at the peak of the growing season; the poor soil represents a sandy soil, the rich soil a deep layer of sapropel); ref.k: Van der Toorn 1972 (min. and max. of 29 sites in August); ref.l: Sieghardt and Maier 1985 (min. and max. of season).

2.4.6.8 Iron and Manganese

Little is known about the habitat characteristics of *Phragmites* concerning iron(Fe) and manganese (Mn). Lanning and Eleuterius (1985) measured in 5 sites the concentration in water of Fe and Mn. The range for Fe is 0.15-0.42 mg/l and for Mn 0.05-0.09 mg/l.

No data are available for the Fe and Mn concentrations in soils in a *Phragmites* stand.

Concentrations of Fe and Mn in *Phragmites* tissues are presented in Table 22.

TABLE 22. Ranges of Fe and Mn concentrations in different organs of *Phragmites australis* in $mg.kg^{-1}$ dry weight.

ORGAN	Fe		Mn		REFERENCE
rhizomes	300	(545.18)	57.0	(52.63)	(b)
	370 -	640			(d)
roots	1390	(4903)	253	(278)	(b)
	2730 -	14390			(d)
roothair	1842	(6434)	402	(433)	(b)
underground organs			26	- 232	(e)
stems	120	(88)	59	(61)	(b)
	110 -	160			(d)
			10.2 -	51.5	(e)
leaves	136	(129)	166	(125)	(b)
	100 -	360	<50	- 660	(c)
	140 -	330			(d)
			24.7	- 206	(e)
stems + leaves	171		125		(a)
panicle	150 -	190			(d)
			37.0	- 89.7	(e)

ref.a: Auclair 1979; ref.b: Kovacs et al. 1978 (the data between brackets are from 1 year later); ref.c: Allen and Pearsall 1963 (min. and max of 11 sites); ref.d: Ho 1981 (min. and max. of 3 sites); Baudo and Varini 1976 (min. and max. of mean monthly levels from 2 sites during the year).

Iron concentrations were greater in leaves then in stems but were substantially lower than those in roots (Kovacs et al. 1978, Ho 1981). Auclair (1979) reported that the Fe and Mn contents of plant tissues were highly correlated with soil organic matter. Also a high correlation was found between iron in tissues and K, Na and Ca in the soil. The concentrations of Mn, in the shoot of reeds were lowest at the beginning of growth and conformed to rise until seed set whereas the underground portions showed the opposite trend (Baudo and Varini 1976). Ho (1981) reported similar observations for Fe and other nutrients in the stem and leaves of reeds but found no consistent seasonal pattern for the roots and rhizomes.

2.4.6.9 Other Micronutrients

The essential micro-nutrients zinc (Zn), copper (Cu), molybdenum (Mo), and silicon (Si) are discussed with regard to their concentrations in the water in reed stands and to their concentrations in *Phragmites* tissues. Data concerning pollution of heavy metals are discussed later in "Contaminant uptake".

The status of Zn and Cu dissolved in the water in a reed stand is summarized in Table 23.

TABLE 23. Ranges of concentrations of Zn and Cu in the water in a *Phragmites* stand in $ug.l^{-1}$.

	Zn	Cu
surface water	39.9	15.3
interstitial water 0-10 cm	100.0	45.8
interstitial water 10-20 cm	60.1	15.3

These data are from an unpolluted lake (Schierup and Larsen 1981). Other data concerning heavy metal pollution are discussed later. No data on micronutrients are available about the soil condition in *Phragmites* stands.

TABLE 24. Ranges of concentrations of Zn, Cu, Mo, and Si in different organs of *Phragmites australis* in $mg.kg^{-1}$.

ORGAN	Zn	Cu	Mo	Si	REFERENCE
rhizomes	14.0				(a)
	20.72	3.72			(a')
roots	37.0				(a)
	112.0	21			(a')
roothair	55.0				(a)
	136.0	28			(a')
stem	17.0				(a)
	14.0	1.0			(a')
		0.4- 2.2			(b)
	20-45	8 -25			(c)
				6000	(d)
			0.2-0.5		(b)
leaves	22.0				(a)
	20.0	3.0			(a')
		1 - 3.5	0.2		(b)
				52600	(d)
	25-40	25 -32			(c)
stem +	112	3			(f)
leaves		0.2- 2.4	0.2-1.3		(g)
panicle				61500	(c)

ref.a: Kovacs et al. 1978 (ref a' = ref a 1 year later); ref.b: Kufel 1978 (during the season); ref.c: Larsen and Schierup 1981 (during the season); ref.d: Lanning and Eleuterius 1985; ref.f: Auclair 1979; ref.g: Kufel and Kufel 1980 (min. and max. of 37 sites).

The Zn concentrations was reported to be negatively correlated with Na and K in the sediment. No significant correlations existed between Cu and edaphic factors (Auclair 1979). Kufel and Kufel (1980) found no relationships between the concentrations of Cu and Mo in plant tissues and those in the substrate.

Silicium contributes to the physical stability of stems and leaves. The Si concentration represents 65% of total ash in the leaves, 19% of total ash in the stem and 83% of total ash in the panicle (Lanning and Eleuterius 1985).

Seasonal influences in metal content may be important. Zn in leaves and stems and Cu in stems was reported to be at the maximum during the growing season and declined thereafter (Kufel

1978, Larsen and Schierup 1981). Kufel (1978) found a general decrease of metal concentration from May to August. But Cu in leaves was relatively constant throughout the season (Larsen and Schierup 1981). On the contrary Baudo and Varini (1976) reported that the concentrations of Cu in the shoot of reeds were lowest at the beginning of growth and conformed to rise until seed set whereas the underground portions showed the opposite trend.

There is no indication that situations of deficiency in micronutrients arise, not even in a peat soil. This is possibly due to the very extended root system with the numerous highly ramified adventitious roots, which arise from the vertical rhizomes. Especially in a peat soil these roots form a dense mass and have an important function in nutrient uptake (Van der Toorn 1972).

2.5 Ecology

2.5.1 Plant communities

Phragmites australis grows in marshes, swamps, wet waste areas, along bayous, streams, lakes, ponds, and ditches. In Europe it belongs to those plant communities being syntaxonomically classified as Phragmitetea due to the high frequency of *Phragmites australis* in phytosociological reviews (Tuxen 1982). *Phragmites australis* occurs on almost every soil type as long as it is moist enough but appears to do best in firm mineral clays in proximity to the water table. Bibby and Lunn (1982) describe 5 moderately distinct groups in which reed can form extensive mono-dominant stands:

- artificial (clay pits, silt settling lagoons, industrial waste lands, dredged material disposal sites, newborne polders)

- lakeside

- estuarine (upper reaches of estuaries, tidal sections of rivers, with a periodic inundation with brackish water)

- coastal (reed encroachment on occlusions of tidal creeks, rivers and flood plains with a shallow flooding)

- inland

2.5.2 Ecotypic variation

The size of the aerial stems and rhizomes, stem coloration, inflorescence size, and number and weight of viable seeds are obviously influenced by the environment. So *Phragmites australis* is a polymorphic species. Previously proposed taxonomic variations such as *gigantissima, stolonifera* and *flavescens* are apparently ecotypes (Haslam 1972). Haslam (1970b) distinguished two basic populations:

1. restricted

2. optimal.

The one termed 'restricted' consists of short, depauperate plants. The restricted stands occur because of one or more factors creating environmental stress. The optimal populations represent the typical form of *P. australis*. The restricted stands occur on higher grounds where the rhizomes are not submerged in the water. Rhizomes are short because of lack of water and nutrients (Haslam 1972). Upland stands are exposed to frost that may kill buds (Van der Toorn 1971). *Phragmites* in a harsh environment tends to have limited carbohydrate reserve (Buttery and Lambert 1965), which accounts in part for the less viable rhizomes. Shaded *Phragmites* produces a somewhat distinctive ecotype with flaccid leaves and an increased blade weight, while the characteristic ribbing is absent. Excess salinity also produces depauperate plants. The smallest *Phragmites* recorded by Haslam (1970a) had nearly prostrate shoots about 5 to 15 cm long. These plants were growing in hard, rather salty, sandy soil. The optimal populations occur in more favorable environmental conditions and represent the typical form of *Phragmites* (Haslam 1970b, 1970c, 1972). Waisel and Rechaw (1971) obtained seeds from a halophytic population. These germinated in salt water of up to 2.3 % Cl. Germination of seeds from a glycophytic population was severely inhibited at this concentration.

In The Netherlands Van der Toorn (1972) distinguished two different ecotypes based on transplantation studies:

1. a peat ecotype consisting of reed with short shoots and a high shoot density occuring in peat marshes.

2. a riverine ecotype consisting of reed with long shoots and limited shoot density, occuring mainly in fresh water tidal areas.

The riverine ecotype compared with the peat ecotype has (1) a higher above-ground production, (2) a greater tolerance for tidal submergence, (3) less tolerance for ground frosts in spring and (4) a greater sensitivity to infestation by the moth *Archanara geminipunctata*.

Dykyjova et al. (1973) recognized that the nearly cosmopolitan distribution of *Phragmites* must lead to both genotypic and phenotypic variation.

2.5.3 Production

Production of *Phragmites* is dependent on different habitat parameters. Generally it is supposed that the presence of light , and the availability of water and nutrients are important factors for a good reed growth. Reflection of light on the water surface can increase the amount of light which the leaves receive. That is why production on the border of a reed stand is often larger than in the middle (Meulemans 1982). Sieghardt et al. (1984) also found the lowest biomass in the middle. However, Mochnacka-Lawacz (1974a) found that the reed in the middle of the stand was most productive. The reed on the shore was characterized by the lowest biomass values, which she attributes to the periodical inundation with water.

Production can be measured by a lot of parameters e.g. shoot density, shoot diameter, dry weight and fresh weight of total biomass or of particular plant parts, height of the reed, number of leaves per shoot, and growth rate. Relations between these parameters and effects of fertilizers, water level, interaction with other species, and management will be considered. Several of the ways to estimate biomass are destructive and time consuming. Ihse and Granelli (1985) developed a method to estimate reed biomass through spectral reflectance measurements. They found a linear relationship between the reflectance ratio and the dry weight of the green biomass per m^2.

There seems to be a relation between the log of the shoot diameter and the log of the shoot density. This relationship is the result of an influence via the rhizome. In spring first the thickest buds develop, depressing the development of other buds (Mook 1982). The potential weight of a particular shoot can be estimated by its height and by its diameter. And so the potential crop can be calculated for each combination of shoot density and mean shoot height (Kauppi et al. 1983) and of shoot density and mean shoot diameter (Mook 1982). This value is always similar, average 2250 g(dr.w.).m^{-1}. But during the season in the field usually lower values are found at high shoot densities. Mook (1982) described this phenomenon of self-thinning as follows:

> "When the plants have reached a certain height, the density decreases because some plants die off. Smallest plants die first. So the mean plant weight increases, but at the same time the plants keep growing and it appears that the total biomass per m^2 increases with decreasing shoot density. Tests indicated that the status of nutrition has no influence on the rate of thinning, but only determines how far the thinning goes on. Damages give a tendency to increase the density the next season. This increases its competitive power, depressing the invasion of other species. On the other hand absence of damage gives a tendency to decrease the shoot density gradually and so on the potential crop will increase."

Van der Toorn and Mook (1982) and Mook and van der Toorn (1982) describe the effects of various environmental agents that cause damages on reeds and their effects on biomass relationships. They studied an experimental field over a period of 5 yrs. Three treatments were applied: burning in spring, mowing and removal of shoots in winter and no disturbance. Each of the three treatments were applied in a wet as well as in a dry area. Also other damages occured caused by ground-frost and presence of moth larvae. The reaction on damage appeared to be essentially the same, regardless of its cause. An early damage, as caused by burning and early ground-frost (end of April, beginning of May), leads to replacement of shoots arising from underground nodes;

late damage, by a moth and late ground-frost (end of May) leads to the formation of side shoots on the aboveground nodes. During the season self-thinning of shoots was found in the treatments that showed high shoot densities as result of damage by burning and by early ground-frost.

Shoot densities range normally from 100 - 400 shoots.m^{-2}. Extremes for aboveground biomass of *Phragmites australis* are 600 g (dr.w).m^{-2} (Dykyjova and Kvet 1978) and 3975 g (dr.w.).m^{-2} (Ho 1979). But, for temperate regions most values vary between 1000 and 3000 g.m^{-2} (Ingram et al. 1980).

Dykyjova and Kvet (1978) compiled from several authors some production data for *Phragmites*. The extremes between these data exist are given in Table 25.

TABLE 25. The ranges of seasonal maximum biomass (fresh weight) and net production of aboveground and underground plant parts of *Phragmites australis*.

	SEASONAL MAX. BIOMASS $g.m^{-2}$	NET PRODUCTION $g.m^{-2}.yr^{-1}$
aboveground (S)	600-3500	600-3700
belowground (R)	1600-8000	500-3000
total	2200-9500	1100-6700
R/S biomass ratio	0.9- 2.0	
R prod./ S biom ratio		0.5-1.0
average ash content	10 %	
Net org. production	1000 - 6000 $g.m^{-2}.yr^{-1}$	

Belowground production was estimated by Roman and Daiber (1984) as the annual increment (max. biomass - min. biomass). This resulted in a mean value of 5800 $g.m^{-2}.yr^{-1}$. Hopkinson et al. (1978) give a loss rate of dead *Phragmites* material of 4.7 mg . $g^{-1}.day^{-1}$.

It is clear that the R/S ratio is much higher in winter. In the literature their is some confusion about the use of root/shoot ratio, rhizome/shoot ratio and total underground biomass/shoot ratio. Dykyjova and Kvet (1978) analyzed some of these ratios and found that:

> "the rhizome/shoot ratio seems to be small in biotopes with a fluctuating water level, which become limosal to terrestrial in late summer to fall: but this ratio becomes three times higher in biotopes with a stabilized hydrological regime. The dependence of the root/shoot biomass ratio on habitat seems far less clear. The total underground biomass, however, seems to be positively related to the supply of mineral nutrients from the soil, especially to that of nitrogen (regression coefficients of 0.787 and 0.884 for rhizome and root biomass respectively): the root biomass was positively correlated to the content of total carbon in the soil."

The amount of soil which is available to one seedling has a great influence on its development. Szczepanska (1977a) tested three different levels of soil volume ranging from 15 l to 100 l. The surface area was in all levels the same. All values of the following parameters: mean height of 3 highest shoots in the pot, number of shoots produced, dry weight of aboveground part of the plant, dry weight of the aboveground parts of the plants per m^2, increased. The dry weight of one shoot in the pot increased to the third level, after which it decreased, due to self-thinning.

The effect of potassium, nitrogen and phosphorus on the production of *Phragmites* has been studied by Ulrich and Burton (1985) and Bornkamm and Raghi-Atri (1986). They found potassium to have no significant effect on biomass. But nitrate and phosphorus both stimulated strongly plant growth. Bornkamm and Raghi-Atri (1986) growed *Phragmites* plants from the field in quartzsand with a nutrient solution with different N- and P-levels. As compared with the standard solution (2.88 mM N l^{-1} : 1.43 mM P l^{-1}) low levels of N (0.14 mM l^{-1}) gave a clearly lower shoot length after the third year, whereas the high N level (14.76 mM l^{-1}) gave a higher shoot length. At the high N level the shoots also were thicker but seemed to break more easily as compared with the standard level (Raghi-Atri and Bornkamm 1980). High additions of phosphorus (16.62 mM l^{-1}) had a dragging effect on shoot length and shoot density in the first year of culture (Bornkamm and Raghi-Atri 1986). High P levels also caused thin stems, with less sklerenchyma and a lower specific weight than the stems from solutions with the standard (1.43 mM P l^{-1}) or low (0.14 mM P l^{-1}) P level. Consequently they also broke more easily (Raghi-Atri and Bornkamm 1980). However, in other investigations (Raghi-Atri and Bornkamm 1979), the same authors demonstrated that high P level can induce thick and thin stems.

Also the presence of other species will have an effect on production. In a comparative study during 4 years of a monoculture of *Phragmites* with mixed cultures with *Carex hudsonii* (Szczepanska 1977b), the mean height of *Phragmites* and its number of shoots were higher in the monoculture. The weight of one shoot was slightly lower in the monoculture in the first 2 years but higher afterwards. Also in experiments with *Typha latifolia*, *Phragmites* is not favored by a presence of *Typha*, in growth rate as well as in production (Szczepanska 1977c).

2.5.4 Decomposition

Especially in reed stands, which are often more or less monospecific, the nature of its decomposing plant parts may act a role itself in the habitat. Each autumn the aboveground biomass will die off. Individual rhizomes can live 3 - 6 or even more years (Haslam 1973).

Imhof (1973) estimated that in a *Phragmites* stand with an energy fixation of 63,000 $kJ.m^{-2}.yr^{-1}$, the majority of the production is utilized by the microbial decomposers. Only a small portion of the energy is apparently utilized by phytophages, and the estimated intake by insects is 170-250 $kJ.m^{-2}.yr^{-1}$.

In a review on the decomposition of aquatic macrophytes Polunin (1984) gives full attention to the way microorganisms and detritivorous invertebrates act in this process. Best (1982) studied the changes in chemical composition of *Phragmites australis* leaves during decomposition under laboratory conditions. Analyses of the water in which dead reed leaves have been immersed during up to 147 days, showed that total carbon and total nitrogen increased more than in the controls. NO_3-N decreased, while NH_4-N increased initially, but decreased later. These increases of C and N were clearly due to the presence of bacteria in the mud, but also the leachate of the decomposing plant litter increased the nitrogen concentration of the overlying water. Decomposition is highly influenced by the salinity. The higher the salinity, the lower the decomposition rate (Reice and Herbst 1982). A comparison of the decomposition of *Phragmites* leaves in clean streams with the decomposition in a stream polluted with industrial, municipal and agricultural wastes and with a high phosphate concentration, resulted in a lower decomposition rate for the polluted stream (Herbst and Reice 1982). It was also found that the colonization rate by macroinvertebrates was lower in the polluted stream. The phenomena of colonization rate seemed to be more important for decomposition than the faunistic composition, richness or diversity. *Larsen and Schierup (1981) found a faster* decomposition in the sewage-polluted lake than in the oligotrophic lake, however.

The deposition of organic matter in a reed stand can also be of an allogenic character. Especially emergent plants enhance the accumulation of organic matter by increasing deposition and reducing erosion. On high tidal marsh dominated by *Phragmites* an annual rate of 17.1 mm has been estimated (Polunin 1984).

When plant remains are added to the substrate, biomass production of young *Phragmites* plants is depressed (Szczepanska 1977b). This occurs mainly during the first weeks of decomposition, when phytotoxic activity may be higher. Thus 20 g *Phragmites* litter per l mud reduced the production by one seedling of *Phragmites* during 3 months from 0.63 to 0.004 g dry weight. However in nature it will rarely happen that substances of dying plants affect young plants, because the period between autumn and next spring may be sufficient for leaching and decomposition of phytotoxic substances (Kuiters 1987).

2.5.5 Succession

Phragmites australis is a common reed swamp species that usually falls between the hydrophyte and shrub (carr) stages of a hydrosere (Haslam 1972). The tangle of rhizomes and adventitious roots requires extensive space, leaving little room for invaders. Buildup of litter within the stand discourages seed germination of other species (Haslam 1971a). Additionally, optimal populations normally consist of pure stands. *Phragmites* can grow in water depths that discourage most invaders. *Phragmites* can invade bare areas created naturally or by men. However, invasion does not normally occur if an area is inhabited by other species. Also a salt marsh, of which the *normal* tidal prism has been restricted, will change in a *Phragmites* dominated marsh (Roman et al. 1984). Where *Phragmites* grows in a tidal area, rapid accumulation of silt may lead to a rising of the land level, which can confine flooding to spring tides (Bibby and Lunn 1982).

But *Phragmites* will tend to persist in areas it no longer dominates (most mixed stands). Then, shoots from 3-year rhizomes are small and 4-year rhizomes are mostly dead. While in a pure stand individual rhizomes live 3 - 6 or more years (Haslam 1973). Where *P. australis* is the sole dominant, shoot density is usually over 100 per m^2. However, annual variations in density and height are considerable, depending upon conditions of the previous year (horizontal rhizome and wide bud development) or the current environmental status (Haslam 1970b).

Drainage causes a lower plant height and smaller plant density (Kamio 1982). When a pure stand of *Phragmites* is drained, silted in or loses the ground cover of water by other means, competitors will appear. *Phragmites* will tend to cease invasion, but will persist for a long time in most normal successional sequences. A successional study of sedge-meadow by Weaver (1960) illustrates this point. Reinink and Van der Toorn (1975) and Van der Toorn (1982) concluded that good reed growth is possible even in dry areas were the water level fluctuates between -30 and -90 cm in summer and between -20 and -30 cm in winter. However growth is restricted by frost and insect damages. Presence of reed leaf litter and reed itself inhibits germination of seeds of other species (Van der Toorn and Reinink 1978). As conditions become more xeric, the plants become more depauperate. Invasion of a stand of *Phragmites* by broad-leaved species would, because of more shading of young reed shoots, decrease the persistance of *Phragmites*.

Also grazing by vertebrates like nutria (Boorman and Fuller 1981) or invertebrates (Van der Toorn and Reinink 1983) can cause a decline of the reed tolerating an invasion of other species. When the reed stand was burned, which killed the insects, succession was stopped and no invasion of other species occured (Van der Toorn et al. 1983).

When *Phragmites* was cultivated with *Typha latifolia* (Szczepanska 1971; Szczepanska and Szczepanski 1982), *Schoenoplectus lacustris*, *Equisetum limosum* (Szczepanska 1971) or *Carex hudsonii* (Szczepanska 1977a), its production was reduced considerably.

2.5.6 Diseases

Numerous fungi have been isolated from *Phragmites*, primarily from dead and decaying aerial shoots. Fungi on the upper sections of the submerged portions of old culms possibly are responsible for the eventual weakening and fall of the stems (Taligoola et al. 1972, Apinis et al. 1972). Haslam (1972) gives an extended list of the occurence of fungi. She listed 12 ascomycetes, 3 basidiomycetes and 16 fungi imperfecti. *Claviceps* infection is common, especially in wet summers e.g., up to 20% in Switzerland (Hurliman 1951) and to 50% in Britain (Haslam 1972). In addition, *Claviceps* has been noted on *Phragmites* in Sweden (Gustafsson and Simak 1963) and in Britain (Mantle 1969). *Ustilago grandis* has been reported in Europe (Durska 1970, Krolikowska 1971). Infested shoots have shortened internodes and a lower transpiration, that can decrease to 1/3 of the value characteristic of healthy plants (Szczepanski 1978). Infestation by the rusts *Puccinia phragmites* and *P. magnusiana* causes a disturbed nitrogen utilization. The decrease of N content in leaves is proportional to the infestation and can be decreased by

30% on the average.

Deightoniella arundinacea and *Steneotarsonemus phragmitidis* can reduce the breaking strength of the stems by causing a lack in the thickening in the stem and warts at the base respectively (Haslam 1973). Various insects have larvae growing in reed stems. In Britain they are called reed bugs. Severe infestation of *Arenostola phragmitidis* occurs in those sites, which have a large amount of litter as the egges overwinter on litter (Haslam 1973). Damage is slight to moderate but can rise up to an 80% kill. As reed bugs eat the meristems and young tissues and as infestation is usually in the lower 30 cm of the stem, only young shoots tend to be destroyed (Haslam 1970a). In The Netherlands, *Lipara lucens*, a fly, is restricted to *Phragmites*. Eggs are deposited on the leaves. The larva induces a gall in the shoot apex where it overwinters. Normally plants with a small (3 to 4 mm) diameter are attacked (Mook 1971). *Giraudella inclusa*, a gall midge, forms no gall but the larvae live in the stems in structures resembling rice-grains (Haslam 1972). Mook (1971) examined reed stems in the polder Zuidelijk Flevoland, The Netherlands; 53% of the stems contained these larvae. Thicker stems were more often attacked and contained more larvae per stem than stems of smaller diameter. Archanara spp is a moth whose larvae bore into and devour inner tissues of the internodes of young shoots (Durska 1970). The larvae occurred in 41% of the stems observed in The Netherlands (Mook 1971). *Archanara geminipunctata* has a strong preference for wide shoots as pupation does not take place in shoots with a diameter less than 5.5 mm (Van der Toorn 1979a). Infestation causes retarded growth of leaves and shoots and lowered the maximal shoot biomass by 25-35% (Mook and Van der Toorn 1982). It can kill up to 80% of the apical parts of the reed shoots (Mook and van der Toorn 1985). Burning and mowing in winter destroys and removes the eggs, which overwinter on the reed shoots. As the larvae do not migrate to other plants after hatching in May, these treatments control the moth (Van der Toorn and Mook 1982). *Rhizedra lutosa*, another moth, whose larvae live in and feed from the rhizomes may also prefer the widest rhizomes. Heavy infestations gave losses in yield of 45-60% (Mook and Van der Toorn 1982). After a season with heavy infestation with both of these moth species, the rhizomes have narrower shoots in the next spring (Van der Toorn 1979a). *Rhizedra lutosa* can not survive in wet habitats, so infestation with this species is only important in dry areas (Van der Toorn and Mook 1982; Van der Toorn et al. 1983). *Hyalopterus pruni* is an aphid that uses *P. australis* as a secondary host, with *Prunus* being the primary host (Mook 1971).

2.5.7 Mechanical limitations

Although *Phragmites* has the capability to grow extensively in bare soils of almost every nutrient status, as long as the water level is high enough, there are several natural mechanical factors which restrict stands. So, *Phragmites* has a low tolerance for both strong wave and current action (Haslam 1972). When reeds are broken off by wave action, the rhizome is impeded which prevents proper bud formation (Haslam 1970c). Where *Phragmites* grows in a tidal area, rapid accumulation of silt may lead to a rising of the land level, which can confine flooding to spring tides (Bibby and Lunn 1982).

Also biological factors can result in mechanical limitations. Within the last several years, pollution in some Swiss lakes has become severe and has produced thick mats of algae. As the water level decreases, the mats are stranded and crush the young aerial shoots of *Phragmites* (Klotzli 1971). The effect of grazing by vertebrates and invertebrates has been reported already in "succession".

2.6 Propagation

2.6.1 Generative propagation

The amount of seeds produced by reed can be very large but also very variable (Szczepanski 1978). Viability and germination is very variable. Seed germination is highly variable, ranging from very poor to 100% (Haslam 1972). Gustafsson and Simak (1963) used X-ray photography to determine viability of seed. Only 5% of all florets photographed were viable.

For seed germination and proper seedling development, certain conditions must exist. The soil must be wet, at first, not flooded more than approximately 1 cm depth (Haslam 1971c, 1972). Szczepanski (1978) still found germination with a water cover of almost 1 m, although it was retarded by 45 days. Severe frost must be absent. Optimal germination also requires high levels of light and temperature ($25 - 35\ ^{o}C$) (Van der Toorn 1972). Rate of germination is temperature dependent: at low temperature germination time is prolonged (Szczepanski 1978). Application of varied temperatures ($20\ ^{o}C$ during 8 h light and $10\ ^{o}C$ during 16 h dark) gave a maximal germination (Van der Toorn 1972). The nitrogen and phosphate content of the soil must be high too. If the water is more than 3 cm below a seedling, phosphorus deficiency occurs. Open areas are necessary. Seedlings may occur in areas recently disturbed by man or in upland areas where plants have been removed by frost. But there, they are usually not successful, as competitors appear later in the year and shade out the seedlings (Haslam 1971c, 1972).

Time of dispersal also is important, which takes place under natural circumstances at the beginning of winter. Szczepanski (1978) noted that it was not possible to induce germination before mid February.

Chapman (1960) found best germination in 1% NaCl. Seedlings, however, require less than 0.5 % salt water for adequate survival (Haslam 1971c, Harradine 1982). Waisel and Rechaw (1971) obtained seeds from a halophytic population and these germinated in salt water of up to 2.3 % solution. Germination of seeds obtained from a glycophytic population was severely inhibited at this concentration.

Seed planting is discouraged because of the low germination rates (Haslam 1972). However, in The Netherlands *Phragmites* has been sown on very large areas in the newly reclaimed IJsselmeer polders, in order to make the soil more suitable for agricultural crops (see: "Use by men") (Van der Toorn 1982).

So, seed germination and seedling development is dependent of a variety of factors:

- the fertility of the seed: low in high polyploid level
- abnormal pollen formation
- injury by insects of seeds and panicles
- unfavorable weather conditions during flowering and seed ripening.
- during germination
    * temperature regime
    * light
    * moisture
    * salinity
- during seedling development
    * *additional N and P supply*

2.6.2 Vegetative propagation

Vegetative reproduction can take place in two ways, i.e. from buds in the rhizomes and regenerative from meristemic tissue in shoot nodes. The last way is common in places where reed is grazed or damaged by the moth *Archanara*. It is also possible that additional shoots are formed on broken stems floating in water. Each node can develop into a new shoot (Szczepanski 1978).

Vegetative extension is strongly promoted by stolons, the creeping shoot at the periphery of the reed plant, growing on rather bare ground. Artificial sowing by airplanes on the newly reclaimed polders in the IJsselmeer, The Netherlands, produced only a few seedlings per are; these formed a dense reed mat within three years by means of stolons (Van der Toorn 1972).

It is important for young plants to develop 10-12 shoots with subsequent rhizomal development to survive frosts. The young shoots may be killed, but if frost-tolerant horizontal rhizome development has occured, new shoots will be produced.

Old reed beds may be very old (ca. 1000 years). Vegetative spread is here considerable (Haslam 1973).

Commercial propagation may be accomplished by seed or portions of rhizomes (with or without roots) before spring growth is initiated. Young green shoots may be planted in May or June. Rhizomes bearing dead aerial stems and transplanted in spring provide the best results (Haslam 1972). Veber (1978) gives an extended survey on the *artificial propagation and cultivation of Phragmites*. Different types of vegetative propagation are discussed as by

1. dividing a reed stolons,

2. layering reed shoots,

3. stem cuttings, where the nodal meristems remain intact,

4. rhizome cuttings

Propagation by seed is also discussed.

Photo 3. Dead reed stems covering part of Times Beach, awaiting decomposition. Courtesy Joop M. Marquenie.

Photo 4. Harvest of reed stems for thatching and fencing in the Netherlands. Debris is burnt in order to prevent deseases and to maintain the reed stand. Courtesy Pim de Kock.

Chapter 3

Contaminant uptake

Phragmites australis can withstand environmental extremes (Kufel and Kufel 1980) including the presence of toxic contaminants and, thus, may be the first plant to invade and vegetate successfully areas which cannot support the growth of other plant species (Ricciutti 1983). The invasion of disturbed areas by reed beds represents an important stage in hydroseral succession (Ingram et al. 1980, Bibby and Lund 1982) which entraps sediment and organic debris and prevents erosion, thus forming the initial process of natural restoration of a disturbed wetland to productivity. The establishment of reed beds, thus, may represent a significant step in the reclamation of wetland creation and confined upland disposal sites containing contaminated dredged material. Very little is known about the uptake of contaminants by reeds, the physiological effects of contaminants on the growth and development of reed beds, or the potential for contaminant entry into the food chain via reed beds.

3.1 Heavy metals

Most of the literature on heavy metal accumulation by *Phragmites australis* is concerned with trace metals essential for plant nutrition, especially copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn), of which only Cu and Zn are commonly cited as being toxic in higher concentrations. Table 26 summarizes the concentrations of these and seven other metals that have been analyzed in reeds.

TABLE 26. Ranges of concentrations of Zn, Cu, Pb, Cd, Sr, Al, Cr, Co and Hg in different organs of *Phragmites australis* in $mg.kg^{-1}$.

ORGAN	Zn	Cu	Pb	Cd	REF.
rhizomes	14.0				(a)
	20.7	3.7	2.5		(a')
	37.9	2.1	<1.0	0.22	(h)
	31.4	3.1	<1.0	0.07	(h')
roots	37.0				(a)
	112.0	21	14		(a')
	244.5	10.8	9.2	1.22	(h)
	118.0	14.3	3.4	0.26	(h')
		35.5- 193.5			(k)
roothair	55.0				(a)
	136.0	28	25		(a')
underground organs		85.3- 379			(l)
stem	17.0				(a)
	14.0	1.0	1.0		(a')
		0.4- 2.2	0.3-3.5		(b)
	45	25			(d)
	47.8	2.4	<1.0	<0.03	(h)
	25.4	1.3	<1.0	<0.03	(h')
		13.8- 577			(l)
		8.1- 24.3			(k)
leaves	22.0				(a)
	20.0	3.0	3.0		(a')
		1 - 3.5	1 - 2.1		(b)
	25 -40	25 - 32	0 -17		(c)
	33.7	3.1	<1.0		(h)
	40.1	2.5	<1.0		(h')
		14.7- 624			(l)
		11.8- 26.5			(k)
stem +	112	3			(f)
leaves		0.2- 2.4	0.4- 2.6		(g)
	24.8		4.4		(i)
panicle		58.4			(m)
		174 -3323			(l)

TABLE 26. Concluded

ORGAN	Sr	Al	Cr	Co	Hg	REF.
roots	37					(a')
roothair	63					(a')
underground organs			2.00-16.0			(l)
stem	1.0					(a')
				0.2-0.8		(b)
			0.64-1.98			(l)
leaves	13.0					(a')
		10-220				(e)
				0.4-1.0		(b)
			2.06-3.62			(l)
stem +					0-35000	(j)
leaves				0.2-1.6		(g)
panicle			4.16-9.00			(l)

ref.a: Kovacs et al. 1978 (ref.a' = ref.a one year later); ref.b: Kufel 1978 (during the season); ref.c: Larsen and Schierup 1981 (during the season); ref.d: Lanning and Eleuterius 1985; ref.e: Allen and Pearsall 1963 (min. and max. of 11 sites); ref.f: Auclair 1979; ref.g: Kufel and Kufel 1980 (min. and max. of 37 sites); ref.h: Larsen 1983 (Lake Hampen; ref.h': Lake Sorteso) ref.i: Gunnison 1978 (from dredged spoil); ref.j: Sarkka et al. 1978 (from 4 sites, on 3 dates); ref.k: Chiaudani 1969 (min. and max. of 18 sites); ref.l: Baudo and Varini 1976 (min. and max. of mean monthly values at 2 sites, during the year); ref.m: Odum and Driffmeyer 1978.

Accumulations of Cd, Cr, Cu, Pb, and Zn generally were greatest in the roots and/or rhizomes and decreased in the above-ground plant parts. The essential trace metals were more mobile within the plants in contrast to Cd and Pb, which apparently translocated very poorly. The general trend was not consistent, however. Baudo and Varini (1976) found the highest mean concentrations of Cr (6.23 ug.g^{-1}) and Cu (1466 ug.g^{-1}) in the inflorescence and the highest Mn (93.2 ug.g^{-1}) in the leaves. Schierup and Larsen (1981) also reported a high Zn content (150 ug.g^{-1}) in the upper 20-40 cm of the stem, which contains the inflorescence.

High concentrations of metals in plant tissues reflected both the relative plant availability of the metals in sediment

(Schierup and Larsen 1981) and the degree of contamination of that sediment (Chiaudani 1969). The Cu content of leaves apparently is well regulated by the plant at environmental levels below the acute toxicity threshold, as Cu levels were similar in the leaves of plants growing on sediments of different Cu content (Chiaudani 1969). Plants growing in more contaminated areas generally had elevated levels of heavy metals in the tissues in comparison to plants growing in less contaminated areas, as would be expected (Baudo and Varini 1976, Chiaudani 1969, Larsen and Schierup 1981). Kufel and Kufel (1980) found that Pb in tissues tended to increase with increased Pb in the substrate. Larsen and Schierup (1981) concluded that "the amount of heavy metals present in the rhizosphere of sediments may considered to be the amount potentially available to plants." Data were unavailable for the overall distributions of Hg, Mo, and Ni within *Phragmites* tissues.

Substrate characteristics may significantly influence the uptake of trace metals by reeds. Schierup and Larsen (1981) suggested that the higher pH, lower redox values and higher organic contents (thus high CEC) of Lake Sorteso (Denmark) rendered the heavy metals less available than those in Lake Hampen; thus, edaphic factors formed greater plant uptake of heavy metals from lake Hampen sediments, even though metal concentrations in the sediments were lower than at Lake Sorteso.

Kufel (1978) reported that the highest concentrations of Pb and Cu in aboveground portions of reed were found during early summer and declined thereafter; Co declined only slightly throughout the season. Pb content of the leaves increased during and after the growing season, presumably as the result of atmospheric deposition (Larsen and Schierup 1981, Larsen 1983). Also Odum and Driffmeyer (1978) found higher levels of Pb on *Phragmites* leaves at shorter distances from the highway. These levels were increased with a factor 6 in the standing dead leaves and with a factor 24 in the leaf litter.

As compared with another helophytic plant *Typha latifolia* there is a tendency that the maximum levels of Zn and Cu in the underground organs are lower in *Phragmites*. But this results in a same level in the leaves and shoots. Sr seems to be better translocated to the shoots by *Typha* than by *Phragmites* (Kovacs 1982, Taylor and Crowder 1983a, 1983b).

3.2 Organic contaminants

Literature pertaining to the uptake by and effects of organic contaminants from *P. australis* is almost non-existent. Sarkka et al. (1978) reported the uptake of chlorinated hydrocarbons by reeds and other plants in Lake Paijanne, Finland. The ranges of concentrations reported for reeds were 0-267 $ug.kg^{-1}$ (PCB), 0-7 $ug.kg^{-1}$ (total DDT), and 0-4 $ug.kg^{-1}$ (aldrin). The organochlorine content of reeds varied widely with sampling stations (4) and dates (3) with no consistent pattern for plant uptake.

Physiological effects of pesticides on Phragmites also have been reported. Merezhko and Shokod'ko (1978) reported that the accumulation of DDT by reed was dependent upon the concentration of DDT in the environment and that DDT was absorbed to the level causing inhibition of metabolic activities. The levels of pesticide accumulation in the plants were unclear in both of the latter publications, however. Shokod'ko et al. (1978) reported that DDT and BHC (lindane) decreased $^{14}CO_2$ assimilation in *Phragmites* and suggested that these pesticides had a specific effect in photosynthesis as well as a "total toxic effect." *Phragmites* was more resistant to DDT than to BHC. The pressure of DDT and BHC promoted ^{14}C "outflowing into roots" in direct proportion to the pesticide concentrations. The "intensification of assimilates into roots in the presence of DDT and BHC was indicated as a "protective reaction of *Phragmites communis* Trin. to the action of the toxic agent."

Chapter 4

Utilization

4.1 Use by wildlife

The ground under a *Phragmites* stand usually has an abundant cover of litter that provides a habitat for small mammals, insects, reptiles and perhaps a few fishes such as *Ictalurus* spp. (bullhead catfish). Aerial stems provide nesting sites for several species of birds (Benton and Werner 1958, Beck 1971). Burger and Miller (1977) recorded *Plegadis falcinellus* (glossy ibis) nesting in a *Phragmites australis* - *Myrica pennsylvanica* habitat in New York, and building their nests of old *Phragmites* stems. In Australia also ibises (*Threskiornis aethiopica*, *T. spinicollis* and *Plegadis falcinellus*) were found to breed in *Phragmites* (Cowling and Lowe 1981). Both *Sterna hirundo* (common tern) and *Larus delawarensis* (ring-billed gull) were found nesting in *Phragmites* in the Great Lakes. *Larus articilla* in New Yersey was found to nest in mixed stand of *Spartina patens* and *Phragmites* (Burger and Shisler 1980). Although the Clapper Rail (*Rallus longirostris yumanensis*) gives preference to *Scirpus* or *Typha* stands, there are scattered places in the Colorado River Valley where they inhabit *Phragmites* stands (Anderson and Ohmart 1985). In England Wagtails (*Montacilla alba*) like to roost communally in winter in *Phragmites* reed beds (Fleming 1981). Bibby and Lunn (1982) found Bittern (*Botaurus stellaris*), Marsh harrier (*Circus aeruginosus*), Bearded tit (*Panarus biarmicus*), Savi's warbler (*Locustella luscinoides*) and Cetti's warbler (*Cettia cetti*) breeding in reed stands. The Graylag goose (*Anser anser*) builds its nest in reed stands, breaks of reed shoots growing around the nests, and accumulate it as nest-building material (Hudec 1973b). Also smaller birds like the reed warbler (*Acrocephalus scirpaceus*) broods in reeds (Oelschlegel 1984). For the Water Pipet (*Anthus spinoletta spinoletta*) wetlands with *Phragmites* are favored as roosting places (Witt 1982). In Britain reed stands are also used as roosting sites by swallows and certain rails and sparrows (Ingram et al. 1980).

In the Louisiana marshes, *Quiscalus major* (boat-tailed grackles), *Tyrannus* spp. (kingbirds), and *Agelaius phoeniceus* (red-winged blackbirds) occupy the *Phragmites* stands (Eifert 1959). Miller (1967) found that *Xanthocephalus xanthocephalus* (yellow-haired blackbird) is restricted in its nesting sites to emergents such as *Phragmites*.

Although many species of birds find a roosting or nesting place in *Phragmites* stands, only a few feed on it. In 33% of stomachs of Coots (*Fulica atra*) remains of *Phragmites* was found (Borowiec 1975). Geese (*Anser anser*) can eat so much of the reed that they can keep an open vegetation in the marsh (Poorter 1982). Boorman and Fuller (1981) noticed grazing by mute swans (*Cygnus olor*), *Anser anser* and *Branta canadensis* (Canada goose) and *Fulica atra*. Although Kvet and Hudec (1971) describe the effect of grazing as damage. In The Netherlands the reed stands are often visited by geese. The result of a reed stand with an open character is seen as an advantage as it leads to a more differentiated reed marsh vegetation. In spring the geese eat the young shoots, often below the water surface. When the water level is not to high they also dig the rhizomes. During the molting of the wings only reed leaves are eaten. In autumn leaves and rhizomes are eaten. Young seedlings can be pulled out in large amounts. Afterwards they start consuming the rhizomes of the older reed stems (Hudec 1973a, Poorter 1982).

Fromel (1980) stated that reed beds are of great importance for insects and spiders wintering in *Phragmites* stands. Burning and mowing decreased the density of arthropods and can so be of negative influence on the supply of food for migrating as well as for breeding birds.

To the mammals which use *Phragmites* as food source belong the muskrat (*Ondatra zibethicus*) especially when the other habitats become overpopulated (Lynch et al. 1974). *Phragmites australis* comprises a portion of the muskrat's diet throughout the Louisiana coastal marshes with highest consumption occuring in the delta and prairie marshes (O'Neill 1949). According to Errington (1941), *P. australis* is stored by muskrats in Saskachewan marshes and is an important summer food in north-central marshes and lakes. Haslam (1970a, 1972) noted that reed is eaten in Europe by *Myocaster coypus* (nutria, coypu) which eat the rhizomes and young shoots,by *Dama dama* and *Odocoileus* spp. (deer) which eat the shoots, and *Arvicola amphibius*, the water vole, eating the exposed rhizomes and buds. They all do little harm to the reed stand and disturb only small patches (Haslam 1973). On the other hand Boorman and Fuller (1981) contributed a decline of a reed swamp to the grazing by nutria. *Phragmites* is listed by the Peking, China, zoo as a favorite food of the giant panda (Anonymus 1974). Self et al. (1974) found that captive *Odocoileus virginianus* (white-tailed deer) consumed

31.5 g of *P. australis* per day during mixed feeding trials in Louisiana, and that it provides excellent escape cover.

Ondatra zibethicus uses *P. australis* for emergency cover when lower marshes are swept by storm tides (Lynch et al. 1974). Martin (1953) considered the plant to have only low grade value as food for muskrat but to be excellent for their house building.

Joanen (1969) noted that *P. australis* is sometimes a partial constituent of *Alligator mississipiensis* (American alligator) nests.

4.2 Use by men

Phragmites is used in many different ways by men. As agricultural use it is grazed by livestock (Haslam 1972) and used as fodder (Yakubouskii and Merezhiko 1975). In Europe as well as in the United States and Mexico it was often used in household goods and in musical instruments. Other important uses of reed are discussed below.

4.2.1 Use on the stand

4.2.1.1 Dewatering

P.australis, with its high transpiration rate, extensive rhizome formation, and negative geotropism is well suited for sludge dewatering experiments. Sludge accumulated at the Karlsruhe Nuclear Research Station, Germany, was applied over stands of *Phragmites* growing along the banks of the Rhine. After a short period of time only one-quarter of the original one m^3 volume of sludge remained. The procedure was repeated until the buildup approached the nodes of the aerial stems. *Phragmites* formed new rhizomes within the sludge and flourished. successive layers of approximately 4.5 m of sludge have been dumped over certain stands over several years, but the overall height of the *Phragmites* bed has increased only 50 to 60 cm (Seidel 1971).

In the Hachirogata central polder in Japan, also *Phragmites* contributed to the drying and dissication of the marshy and heavy clay soil ground. Seeds were sown by helicopter immediately after the exposure of the lake bottom. In the first year the ground-water table lowered about 19 cm to about 40 cm in the next year (Kamio 1982).

Also in The Netherlands reed has been sown artificially by planes in the newly reclaimed IJsselmeer polders in order to dry the soil. The very deep root system (over 2 m deep) and the high transpiration rate promote dissication and make the soil more suitable for agricultural crop plants. The extended root system makes the initially very weak soil better passable. The reed stand also helps to repress the introduction of other species, preventing the establishing of species, which are unfavorable for agriculture, like *Cirsium arvense* and *Cirsium vulgare*. It appeared that the reed was fairly easily to remove during and after the cultivation (Van der Toorn 1982).

Studies by Lee et al. (1976) indicating potential uses of *P. australis* in filtering and dewatering dredged material. Observations made at dredging sites indicated that the presence of thick vegetation growing on a disposal site helps to decrease the turbidity of the effluent. *Phragmites australis* was found to aid in slurry filtration when naturally present at many diked and disposal sites in fresh or brackish water. As previously observed by Seidel (1971), Lee et al. (1976) found the regenerative ability of *Phragmites* after complete burial up to 2 m of dredged material makes it a prime plant for slurry filtering. The previous authors also found *P. australis* to be useful in dewatering dredged material, particularly in areas where dredged material is deposited frequently.

4.2.1.2 Bank protection

Banks of lakes, canals and rivers are frequently submitted to erosion by wind, waves and boat wash. Although last decennia natural bank protection was replaced for a big deal by materials like concrete, steal or synthetic substances. Presently in many places bank vegetations, which aim at bank protection are developped. The growth potentials for plants in a bank habitat and so the potential to protect the shores are defined by the slope, substrate and waves from boats and wind and by human activities like boat-landings, mowing, grazing by cattle and fishery. Helophytes can protect the bank by (Bonham 1983):

1. absorbing boat wash wave energy

2. maintaining vigor and stability

3. preventing substrate scour

4. encouraging sediment deposition

A reed bed along the bank of 2 to 3 m wide can absorb 60-75 % of the energy from the waves (Bonham 1983). The dense and extended root system will prevent erosion at the bank side of the reed bed; also the thin, though, flexible stems are able to withstand wave action. The outer edge of the bed is prone to scour, however (Bonham 1983). Therefore it is advised to use other species like the Common Clubrush or Bulrush (*Schoenoplectus lacustris*) along the side of the waterway (Van Acht and Sessink 1982), in order to protect the rhizomes of the reed. The reed zone can grow to a maximum of 1.1 m deep. The clubrush zone to a maximum of 2 m deep. This way of planting is applicable at a natural bank with a slight slope. Management of the bank vegetation is usually necessary, especially to prevent infestation by insects. Burning or mowing should be done in early spring with regard to heavy wave action in wintertime (Van Acht and Sessink 1982).

4.2.1.3 Water purification

The use of *Phragmites* stands and other macrophytes in water purification has been treated by numerous authors. This concerns especially the removal of excess of nutrients (N, P) in communal, agricultural and industrial waste water. De Jong et al. (1977) showed that the purification of sewage is based on a breakdown by micro-organisms. The swamp plants function by providing attachment sites for these organisms and by the uptake of nutrients. A more sophisticated form of waste water purification is achieved in the root-zone-method (Brix 1986). A root-zone treatment plant is basically an artificial wetland consisting of a plastic lined excavation containing emergent vegetation growing in soil. In advance treated waste water, which includes the stay in a sedimentation tank must penetrate through the soil and no surface run-off must occur. When it flows through the rhizosphere the wastewater is cleaned by binding and precipitation processes in the soil and by microbiological degradation. The functions of the macrophytes is as follows (Brix 1986):

1. To supply oxygen to the heterotrophic microorganisms in the rhizosphere

2. To increase/stabilize the hydraulic conductivity of the soil

Brix (1986) selected *Phragmites australis* as a very suitable species because of the deep and dense roots and rhizomes, which create a great volume of active rhizosphere per surface area. The direct role in uptake of nutrients is negligible, as the total uptake during one growing season is only a few percent of total inflow (see: "Nutrient uptake"). Also recycling in the system takes place as the result of decay.

The system developed by Wolverton and McDonald (1982) is a combination of a vascular plant system growing in a filter bed containing anaerobic microorganisms. They called this system the "Hybrid microbial filter-vascular plant waste water treatment system". Reed was often used as vascular plant. Complex organics are broken down into simpler compounds, which can be assimilated by the reeds. Odorous volatile sulfides produced during anaerobic digestion are either removed by the plants or converted to sulfates near the surface. Other gaseous products are CO_2 and CH_4 (Wolverton 1982). Methane can be collected and burned as an energy source or the gases flared for odor control (Wolverton and McDonald 1982). Wolverton et al. (1983) compared the effectiveness of *Typha latifolia*, *Juncus effusus* and *Bambusa multiplex* with that of *Phragmites australis* in a similar system. *Phragmites* showed to be superior in removing N, P and suspended solids.

Table 27 gives a summary of the efficiency of removal of nutrients in wastewater by *Phragmites australis*, based on several authors. It would have been valuable if every author had stated the final concentration of nutrients in the effluent in relation to the retention time and the area of the purification plant.

TABLE 27. The influence of the presence of *Phragmites australis* on waste water purification. Removal efficiency (% of influent concentration) of nutrients and solids.

T- : total
Kj- : Kjeldahl
O- : ortho
TSS : total suspended solids
TDS : total dissolved solids
(t) : through soil
(o) : over soil
d : days
m : months

TYPE OF WASTE WATER	PARAMETER	PRESENCE OF REED	REMOVAL %	RETENTION TIME	REFERENCE
sewage	Kj-N	+	99.2	17 d	(a)
		−	98.5		
	NH_4-N	+	100		
		−	100		
	T-P	+	99.3		
		−	99.2		
agricultural and domestic	T-N (t)	+	91.9	123 d	(b)
	(o)	+	87.2		
	(o)	−	69.1		
	T-P (t)	+	77.0		
	(o)	+	73.1		
	(o)	−	64.9		
	K (t)	+	86.4		
	(o)	+	78.3		
	(o)	−	35.1		
domestic	TSS	+	91.4	2 d	(c)
		−	80.0		
	TDS	+	29.3 (increase)		
		−	4.0		
	Kj-N	+	82.0		
		−	27.6		
	NH_3-N	+	95.2		
		−	7.6		
	T-P	+	54.5		
		−	11.3		

TABLE 27 Concluded

TYPE OF WASTE WATER	PARAMETER	PRESENCE OF REED	REMOVAL %	RETENTION TIME	REFERENCE
poultry abattoir	Na	+	81 (incr.)	4 d	(d)
	K	+	55 (incr.)		
	Cl	+	44 (incr.)		
	TSS	+	84		
	Kj-N	+	26		
	NO_3-N	+	60 (incr.)		
	NH_4-N	+	12		
	T-P	+	37		
	O-P	+	28		
domestic	T-N	+	29	13 m	(e)
	T-P	+	17		
	T-N	+	88	15 m	
	T-P	+	94		
	T-N	+	62	15 m	
	T-P	+	83		
	T-N	+	23	4 m	
	T-P	+	31		
	T-N	+	25	4 m	
	T-P	+	18		
	T-N	+	10	6 m	
	T-P	+	11		
	T-N	+	30	14 m (*)	
	T-P	+	38		
	T-N	+	53	12 m (**)	
	T-P	+	45		

(*) with *Typha latifolia* and *Carex acutiformis*
(**) natural wetland

ref.a: De Jong et al. 1977; ref.b: Radoux 1982; ref.c: Wolverton et al. 1983; ref.d: Finlayson and Chick 1983; ref.e: Brix 1986 (comparison of 8 root zone treatment plants in Denmark).

De Jong et al. (1977) found a good removal of N and P from the sewage from a campsite. The presence of vegetation had no clear influence, however except for the reduction of eutrophication of the pond. A comparison of percolation of water through the soil and flowing over the soil has been carried out by Radoux (1982). Three species were used successively: First the water had to flow through a *Typha latifolia* bed, then through a *Phragmites australis* bed and last through a *Carex acuta* bed. The presence of vegetation had a beneficial influence on N, P, K removal, as had the system where the waste water flows through instead of superficially over the soil, so using more of the rhizome volume. In the microbial filter method of Wolverton et al. (1983) the beneficial presence of vegetation is demonstrated. The increase of total dissolved solids is due to the decay of suspended solids. Although Finlayson and Chick (1983) also found a decrease of N, P and suspended solids concentrations in the effluent, the concentration of Na, K and Cl was increased. The lignosulphate concentration in paper mill waste water was also decreased by *Phragmites*. But *Juncus pallidus* and *Typha orientalis* did do it better (Allender 1984).

Most research with regard to the utilization of aquatic macrophytes in waste water purification concerns organic pollution and macronutrients. Little has been done on their possible use for other pollutants. In the case of heavy metal pollution this will force to harvest the vegetation. We have seen that low levels of heavy metals are transported from the root system to the above-ground plant parts of *Phragmites australis*. McDonald compared the efficiency of several aquatic species in decontaminating radioactive soils and water. She showed that cesium, strontium and cobalt were absorbed by the root system of *Phragmites* but just a little was transported to the shoot.

4.2.2 Use after harvesting

4.2.2.1 Energy source

The use of aquatic plants like water hyacinth as energy source has been discussed in terms of methane fermentation. Reeds can be burned directly as a solid fuel because the low water content and the high C/N ratio. In Sweden a large project is runned to use *Phragmites australis* as energy source (Bjork and Graneli 1978, Graneli 1984). The standing crop in a reed stand is in summer 1 kg dry matter m^{-2}; in winter 0.5 kg m^{-2}. Higher maximum biomass values have been reported up to 3.5 $kg.m^{-2}$ (Roman and Daiber 1984), but these are probably not representative for larger areas. The energy content of reed in summer as well in winter is about 5 $kWh.kg^{-1}$ dry matter. This is only 42% of the energy content of oil.

Graneli (1984) explains that lowlying wasteland can often be cultivated with *Phragmites* for local energy use, as large volumes make transportation and storage expensive. In order to make reed more compact several methods are available:

- bales, in the same way as straw (100 $kg.m^{-3}$)
- cutting in chips of 0.5 - some cm (volume weight: 100-150 $kg.m^{-3}$)
- powder (volume weight: 250 $kg.m^{-3}$), this allows automatic burning
- high pressure, transformation to brickets and pellets (density: 1000 $kg.m^{-3}$; volume weight: 500-700 $kg.m^{-3}$).

Graneli (1984) thinks as compared with straw, that the energy input is only 15% of the energy output. Agricultural plants like wheat and potatoes require an energy input of 17 tot 27 %.

For local use reed is an fairly good fuel with a low ash content, a rather high energy content and a low energy input/output ratio. But as it is very bulky the transport costs should be kept low, although a distance of 100 km will not influence the energy budget substantially (Bjork and Graneli 1978).

4.2.2.2 Industrial use

Phragmites is also used for industrial purposes. In Romania (De la Cruz 1978) and the Volga delta, U.S.S.R. (Karzhavina 1975) it is used for cellulose production for the manufacture of paper and other cellulose derivates. The cellulose content is 27-69% and the mean fibre length 0.9-2.0 mm (Haslam 1973). In order to increase the tear strength and density of the paper the reed pulp has to be mixed with wood pulp (De la Cruz 1978).

4.2.2.3 Reed as building material

In the past reed was often used as building material to construct huts, walls or roofs. Now it is still satisfactory used as mats for fences, wind and sun shields, isolating material and especially for thatching. It has a highly decorative value. Houses and buildings thatched with reed are particularly found in Japan and The Netherlands.

Thatching reed of a good quality, which is hard and resistant to decay should be fine and thin (Brandsma 1982) and have a high degree of lignification (Stant 1953). Long stems are produced in stands with a changing water table.

The costs of the thatching of a roof are very high; about Dfl 100.- (begin 1987:US $ 50.-). m^{-2}. A Dutch farm often has a roof of about 300-400 m^2. A thatched roof lasts about 40-45 years and should than be renewed (Loff 1987).

Photo 5. Estuarine *Phragmites* - *Spartina* community at the Field Verification Project (FVP) field site, Bridgeport, CT. Courtesy Joop M. Marquenie.

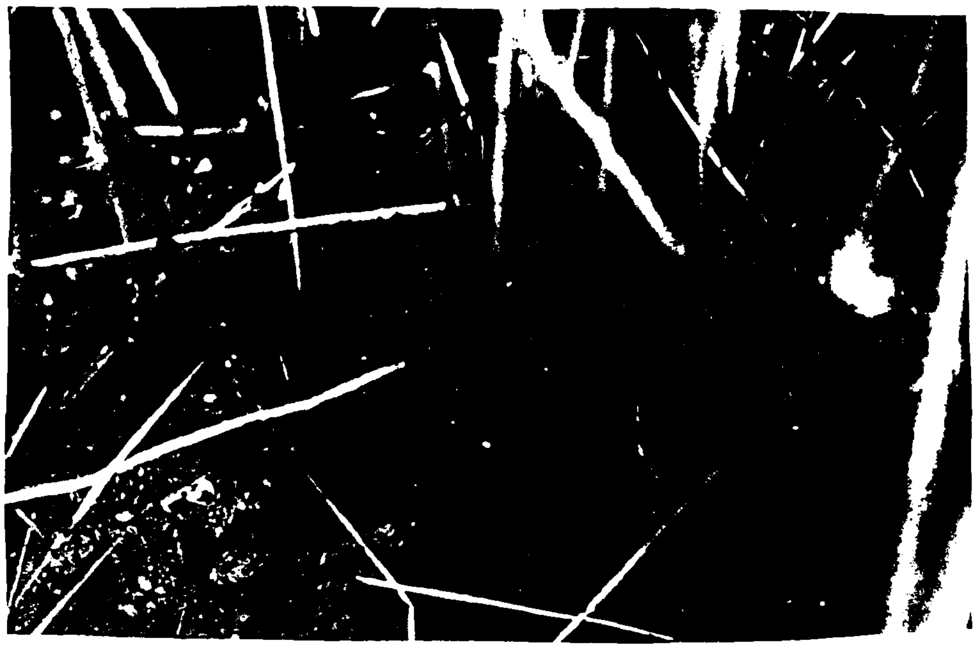

Photo 6. Marine mussels, *Modiolus demissus*, sheltered by active growing stems, rhizomes and roots of reeds. FVP field site, Bridgeport, CT. Courtesy Joop M. Marquenie.

Chapter 5

Management

5.1 Control

5.1.1 Chemical control

Twenty to thirty years ago, herbicides were often used on dense *Phragmites* stands in order to clean waterways or to induce the introduction of other plant species, which were more favored by wildlife. The site was also more suitable for game utilization as the penetrability for wildlife (and for hunters) was increased. An often used herbicide in *Phragmites* stands was Dalapon (Beck 1957).

Due to the greater knowledge at present with regard to the dangers caused by herbicides in food chains, these chemicals are no longer used.

5.1.2 Mechanical control

A combination of drainage and ploughing will prevent recolonization of a reed stand. *Phragmites* will decrease in vigor following drainage. Normal drainage will reduce the number of reed stems but will not completely eliminate them. Often the drainage process will allow competitors to invade the stand and in turn shade out young shoots, which will enhance control (Haslam 1968). The high evapotranspiration of *Phragmites* will actually speed the drying process (Haslam 1970c). Then the weakened *Phragmites* beds should be ploughed to a depth of 20 cm. This method is used in the newly reclaimed polders in The Netherlands in order to prepare the reed stands for agricultural use. For a noticeable control it is necessary to cut the horizontal rhizomes. The short rhizomes produced as an aftermath will produce short shoots that are easy to control (Haslam 1968).

Dredging is effective in control of *Phragmites* if the horizontal and vertical *rhizomes are removed.* If the dredging process leaves a water depth of over 1.5 m, recolonization will not take place unless accretion occurs (Haslam 1968).

Other mechanical and biological *methods are more* used as management procedures in order to create or maintain a reed stand as one likes it. They are not suitable to eliminate a reed stand completely.

5.2 Management

Management of a *Phragmites* is practiced for several reasons.

- To keep the density low as in drainage channels and waterways or in agricultural areas.
- To maintain an open reed stand as for natural conservation reasons or in recreation areas.
- To maintain a dense reed stand as for water purification or reed cultivation
- To keep diseases and insect infestation under control where *Phragmites* is used as bankprotection.

Several methods are available in order to manage a reed stand. Dredging and ploughing have been discussed before. Other methods are grazing, burning, cutting and mowing and active regulation of the water table.

5.2.1 Grazing

Cattle graze young buds and shoots. In combination with trampling which can destroy buds, they can suppress a reed stand. As discussed before waterfowl, in particular *Anser anser* can create and maintain a reed stand with an open character by grazing and is therefore these are preferred in nature conservation projects.

5.2.2 Burning

Fire can be applied at different moments of the growing season. Thompson and Shay (1985) tested the effects of fire on *Phragmites australis* in the Delta Marsh, Manitoba, Canada. They compared different burn treatments: burning in spring, summer, autumn and no fire at all. Standing crop was increased after fall and spring burns, as did the bud density. Burns in summer had no effect. Few damaged shoots were observed after the burns in spring and autumn. Higher total shoot density probably resulted from litter removal, as a thick litter mat reduces shoot density (Haslam 1972). In The Netherlands burning in the emergence period caused severe damage to the buds (Van der Toorn and Mook 1982). But burning in early spring, before bud emergence was favorable in insect control. The eggs of the moth *Archanara geminipunctata* remain on the shoots throughout the winter and after hatching in May, the larvae did not migrate. Also the moth *Rhizedra lutosa* can be controlled by burning, because its eggs overwinter near the shoot base. (Van der Toorn and Mook 1982, Mook and Van der Toorn 1982).

5.2.3 Mowing and cutting

Cutting and mowing are frequently applied in management of reed stands. Except for harvesting reasons (see: reed cultivation), mowing is applied to control the size and area of open water in fishponds (Husak 1978) and waterways.

Winter cutting is normal when the culms are used. This has a favorable effect on the development of the stand (Husak 1978), inducing an increase in stand density and homogeneity. Hansson and Graneli (1984) found an almost doubling of the shoot production. The shoots develop evenly and eggs of the moth *Archanara geminipunctata*, which hibernate on the shoots are removed (Van der Toorn and Mook 1978). Summer cutting does not effect underground biomass and the shoot diameter in the following spring. The reed regenerated by forming side shoots on the primary shoots, so the total number of shoots increased. The shoot biomass decreased, but if the value, reached in October is added to the amount removed in June, the result is not significantly different from the control.

Frequent cutting in one season lowered the biomass significantly (Mochnacka 1974c). Final standing crop after two successive mowings in mid June and mid July is only 3-4% of the unmowed standing crop in mid October. When we add the 1st and 2nd harvest only 40% is reached. Total ash content, Si, Ca and K is not effected in stems due to mowing; but in leaves total ash, Si and Ca are reduced after mowing. K, P, and N are increased after mowing in the leaves and the P and N content also in the stems (Mochnacka 1974).

Repeated winter harvest of reed and removal of dry reed culms during 4 successive winters caused an increased biomass during the growing season and this resulted in a lower phosphate concentration in the water column and sediment interstitial water (Hansson and Graneli 1984).

5.2.4 Active regulation of the water table

Productivity of a reed stand can be decreased by drainage. On the other hand flooding can increase the productivity. Reed cultivation is favored by flooding a plot by a mill. A layer of nutrient rich surface waters on the reed stand from April to July will suppress the introduction of other species (Brandsma 1982).

5.3 Nature conservation

Brandsma (1982) describes several aims of the management of reed stands with regard to nature conservation:

- The maintenance of the reed stand as community.

- The encouragement of the natural process of development into other communities. The maintenance and increasing of the internal variety of flora and fauna in a marshland in its entirety.

So in order to increase or maintain the internal variety of flora and fauna the reed stand should be open, which can be achieved by grazing by geese. At least locally, however, the formation of new succession stadia like peatbogs and woodland should be disturbed. A reed stand can also be used as buffer against the inflow of nutrient rich surface water to make succession possible into oligotrophic stadia.

In reed stands on peat soil the water level has to change as little as possible; it should not be flooded nor burned.

5.4 Reed cultivation

Often the reed grower wants another way of management of a reed stand than is preferred with regard to nature conservation. As described before the reed grower likes to flood the reed soil with nutrient rich water and to treat *Urtica*, *Rubus* and *Convolvulus* chemically (Brandsma 1982). Yearly harvest in winter promotes a dense stand the next year.

5.4.1 Reed harvest

The best time of the year to harvest reed for thatching and reed mat production is in winter from the end of December onwards. For the use as energy source winter harvesting has the disadvantage that only 50% of the biomass can be utilized. On the other hand winter harvesting has several advantages (Graneli 1984):

1. Destruction of rhizomes and dormant buds can be prevented if harvesting is done from ice or on frozen root mat

2. Only small amounts of nutrients are removed from the reed stands, as recycling to the rhizomes has been completed

3. Mechanical reed harvesting methods have been developed. The harvester can move easily and the ground can support a much heavier load than in summer.

4. The culms are harvested with a low water content and do not need drying before used as fuel

5. No serious environmental disturbance occurs.

Graneli(1984) describes several heavy harvesting machines, which can also cut the reed to smaller pieces. They all require an ice layer with a thickness of at least 40 cm. But with snow the harvester jams, the reed stems may crack down and harvesting fails (Loff 1987).

Chapter 6

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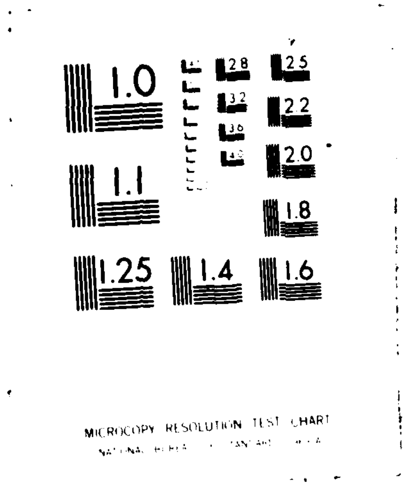
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